AN INVESTIGATION INTO FACTORS AFFECTING THE CHILLED FOOD INDUSTRY

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Abstract

With the advent of Industry 4.0, many new approaches towards process monitoring, benchmarking and traceability are becoming available, and these techniques have the potential to radically transform the agri-food sector. In particular, the chilled food supply chain (CFSC) contains a number of unique challenges by virtue of it being thought of as a temperature controlled supply chain. Therefore, once the key issues affecting the CFSC have been identified, algorithms can be proposed, which would allow realistic thresholds to be established for managing these problems on the micro, meso and macro scales. Hence, a study is required into factors affecting the CFSC within the scope of Industry 4.0. The study itself has been broken down into four main topics: identifying the key issues within the CFSC; implementing a philosophy of continuous improvement within the CFSC; identifying uncertainty within the CFSC; improving and measuring the performance of the supply chain. However, as a consequence of this study two further topics were added: a discussion of some of the issues surrounding information sharing between retailers and suppliers; some of the wider issues affecting food losses and wastage (FLW) on the micro, meso and macro scales. A hybrid algorithm is developed, which incorporates the analytic hierarchical process (AHP) for qualitative issues and data envelopment analysis (DEA) for quantitative issues. The hybrid algorithm itself is a development of the internal auditing algorithm proposed by Sueyoshi et al (2009), which in turn was developed following corporate scandals such as Tyco, Enron, and WorldCom, which have led to a decline in public trust. However, the advantage of the proposed solution is that all of the key issues within the CFSC identified can be managed from a single computer terminal, whilst the risk of food contamination such as the 2013 horsemeat scandal can be avoided via improved traceability.

Acknowledgements

I would like to thank Dr Parminder Singh Kang, Dr Ross Clement and Professor Alistair Duffy for their support throughout this project. This study was made possible via a De montfort University studentship as a part of the AIDMT project.

“Oh God, I could be bounded in a nutshell and count myself a king of infinite space, were it not that I have bad dreams.” *Hamlet* Act 2, Scene 2.

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List of Abbreviations

FLW – Food Losses and Wastage

SME – Small to Medium Sized Enterprise

CFSC – Chilled Food Supply Chain

CPS – Cyber Physical Systems

IoT – Internet of Things

IoS – Internet of Services

TQM – Total Quality Management

AMOR – Alliances for The Mutual Organisation Of Risk

FQMS – Food Quality Management Systems

BAU – Business as Usual

M2M – Many to Many

SCM – Supply Chain Management

LAN – Local Area Network

WLAN – Wireless Local Area Network

WMN – Wireless Mesh Network

WSN – Wireless Sensor Network

RFID – Radio Frequency Identification

EIS – Enterprise Information System

IEIS – Integrated Enterprise Information System

WEIS – Wireless Enterprise Information System

CVRP – Capacitated Vehicle Routing Problem

QAAHE – Quality Assurance Agency for Higher Education

HLPE – Higher Level Panel of Experts

OUT – Order Up To

EDLP – Everyday Low Pricing

OECD – Organisation for Economic Co-Development

DMAIC – Define, Measure, Analyse, Improve and Control

LSS – Lean Sigma Six

MTO – Make to Order

MTS – Make to Stock

BTO – Buy to Order

ATO – Assemble to Order

STS – Ship to Stock

CODP – Customer Order Decoupling Point

DEA – Data Envelopment Analysis

DRC – Dempster's Rule of Combination

PBE – Perfect Bayesian Equilibrium

JGD – Joint Gaussian Distribution

SCOR – Supply Chain Operations Reference

KPI – Key Performance Indicator

KPF – Key Performance Factor

SCS – Supply Chain Structure

BPR – Process Redesign

SS – Supplier Selection

FCP – Facilities/ Capacity Planning

SCI – Supply Chain Integration

ISH – Supply Chain Integration

BE – Bullwhip Effect

RL – Reverse Logistics

RCP – Replenishment Control Policies

SCO – Supply Chain Optimisation

CR – Cost Reduction

SP – System Performance

IPM – Inventory Planning/Management

PFD – Planning & Forecasting Demand

PP-SCH – Production Planning & Scheduling

DTP – Distribution & Transportation Planning

DR – Dispatching Rules

AHP – Analytical Hierarchy Process

FLD – Facility Layout Design

SAW – Simple Additive Weighting

COP – Coefficient of Performance

SEC – Specific Energy Consumption

ASCPPM – Aggregated Supply Chain Process Performance Measures

GSCPPM – Generic Supply Chain Process Performance Measures

NDEA – Network Data Envelopment Analysis

VRS – Variable Returns to Scale

DMU – Decision Making Unit

CRS – Constant Returns to Scale

SFSCM – What is meant by Sustainable Food Supply Chain Management

FSCM – Food Supply Chain Management

HACCP – Hazard Analysis and Critical Control Points

SC – Supply Chain

GM – Genetically Modified

BSE – Bovine Spongiform Encephalitis

DEFRA – Department for Environment, Food and Rural Affairs

MAFF – Ministry of Agriculture, Fisheries and Food

DETR – Department of Environment, Transport and the Regions

EU – European Union

PHE – Public Health England

ACSI – American Customer Satisfaction Index

MAR – Missing at Random

MCAR – Missing Completely at Random

MNAR – Missing Not at Random

NLP – Natural Language programming

NLTK – Natural Language Tool Kit

SQL – Structured Query Language

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Chapter One – Industry 4.0 and the Chilled Food Supply Chain

1.1. Introduction

The structure of this chapter will follow the template as given in Figure 1.1 below:

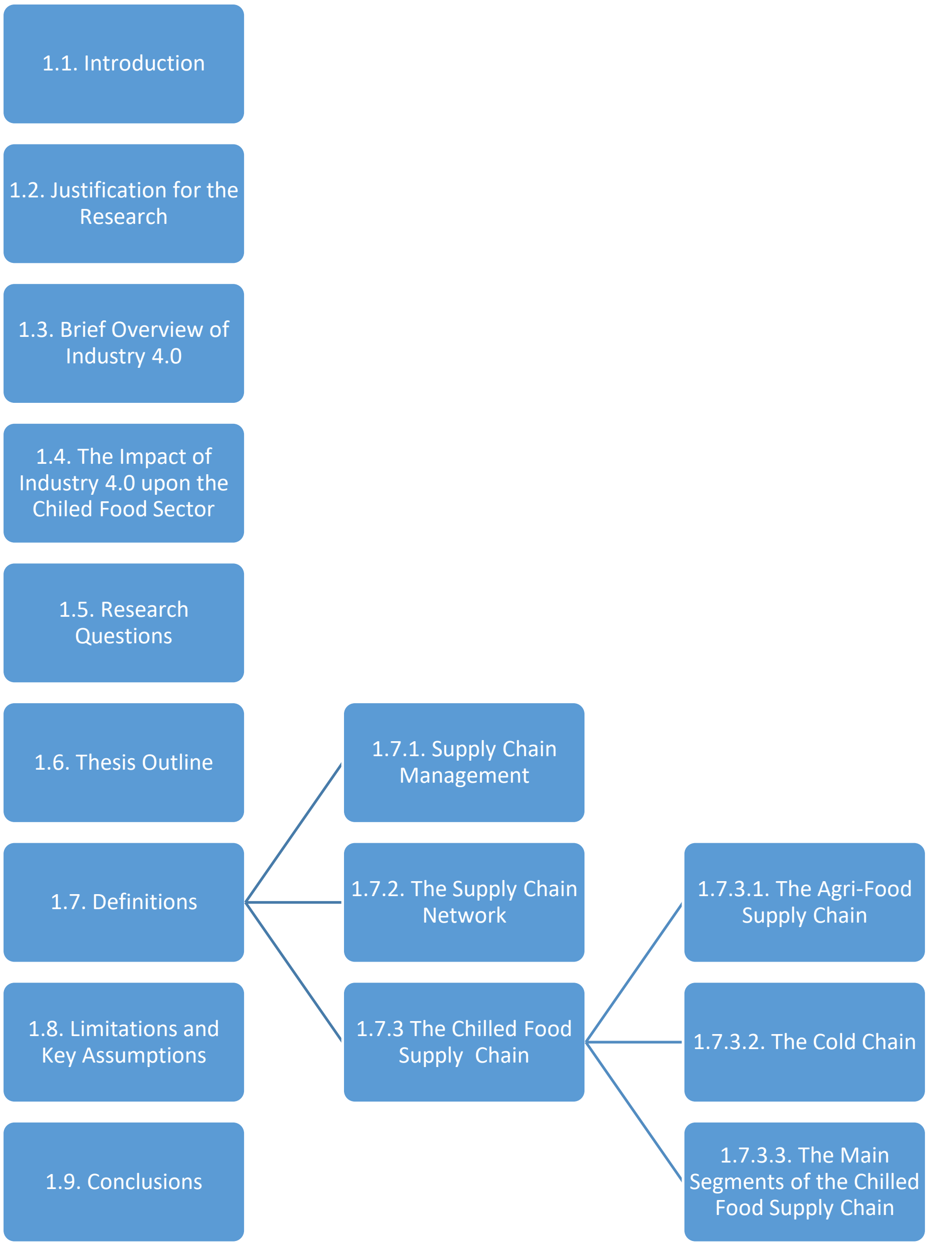

Figure 1.1. Diagram to illustrate the structure of Chapter One.

1.2. Justification for the Research

There is every need for food companies – particularly small to medium sized enterprises (SMEs) – to improve their monitoring capabilities and sustainability practices. Bloom (2010) makes the following pertinent statement:

> There are few studies on food waste partly because there just aren't that many people who want to tally unharvested lettuces – or any other kind of wasted food. There has been little imperative or political will to size up how much food we squander – until now. Plus, waste can be difficult to measure. It's much easier to count what is harvested than what isn't. Because waste disappears quickly in most parts of the food chain, it's much harder to tabulate (Bloom 2010, 10).

Whilst we might consider that food abundance and excess are perceived as symbols of social aspiration – with Post War America signifying the pinnacle of that affluence – from a Lean perspective we recognise immediately that the real issue is that of overproduction. Yet Bloom continues with a description of the now-closed Crazy Horse Canyon landfill in Salinas, central California which had been receiving "200 tons of excess, rejected, or misbagged produce every day until the landfill's closure in 2009" (Bloom 2010, 2). Whilst this level of wastage might appear unacceptable from a British perspective, Bloom also states how "the majority of it was edible at the time it was dumped at Crazy Horse" and that it had been rejected as industrial food waste simply because “it may have been damaged in the warehouse” or “it sat for too long to withstand shipping” (ibid.).

Yet this level of excess also signifies hidden costs, which could have been brought under control through better monitoring and by greater awareness of sustainable (i.e. environmental) practices in waste management. In this context, it follows that food waste management should form an integral part of sustainable practices from the outset.

Similarly, we should also consider the meat adulteration scandal of 2013, in which foods advertised as containing beef in fact contained as much as 100% horse meat (Lawrence 2013). Accordingly, some forms of meat production had “more than 450 critical control points” between the farmer and end consumer within the supply chain (ibid.). Issues like this infer that the chilled food supply chain (CFSC) had become unnecessarily complicated and that the individual firms involved had little perspective of the overall supply chain.

Hence, this study is required not only to aid with the development of a food monitoring system based on Industry 4.0 technology, but also in order to pre-empt any of the many existing issues which currently affect the CFSC.

1.3. Brief Overview of Industry 4.0

Industry 4.0 (or Industrie 4.0) is a collective term for the technologies and concepts of value chain organisation (Hermann et al 2015, 11). The term was first coined at the 2011 Hannover Fair (Kagermann et al 2011). The driving force behind its development is the rapid increase in the digitisation of the economy and society. Industry 4.0 is based on the unification of the following four components:

1. Cyber-Physical Systems (CPS) – i.e. the fusion of the physical and virtual environments;
2. Internet of Things (IoT) – i.e. the network which allows CPS to communicate with each other;
3. Internet of Services (IoS) – i.e. the infrastructure for services, business models, and participants, to operate via the Internet;
4. Smart Factory – i.e. a factory that assists people and machines in execution of their tasks (Hermann et al 2011, 7).

For further information on Industry 4.0 see (Hermann et al 2015; Kagermann, 2014; Lee 2008; Bauernhansl 2014; Scheer 2013).

1.4. The Impact of Industry 4.0 upon the Chilled Food Sector

The application of Industry 4.0 to the chilled food sector has the potential to:

1. Improve resource efficiency and/or waste minimisation – given that food losses and wastage (FLW) is now considered a global crisis (HLPE 2014).
2. Improve measurement and control of processes across the CFSC.

The following brief literature search anticipates the need for this kind of application.

Fuentes-Pila et al (2007) suggest that while Lean Manufacturing and other Total Quality Management (TQM) improvement methodologies such as Six Sigma have been applied by large companies in the agri-food sector, there is little information on these applications available in the scientific literature. One particular reason why TQM has not been widely adopted by the agri-food industry is due to the inherent uncertainty of the products, such as eggs being laid of different sizes and yields (Fuentes 2007, 315).

Van Plaggenhoef (2007) states that although research interest in supply chain management is growing only a few studies have been focussed on quality management practices in a supply chain management perspective. In addition, due to the various food crises – e.g. BSE, dioxin, swine fever, foot-and-mouth disease, H2N1 or “bird flu” – ethical concerns have been raised and consumers are demanding more information about the food they buy.

Marucheck et al (2011) discuss product safety issues and the challenges that arise across five industries that are globalising their supply chains – food, pharmaceuticals, medical devices, consumer products and automobiles. Accordingly, there are four areas where operations management theory and methodologies can provide fresh insights and innovative solutions in addressing these problems:

1. Regulation and standards.
2. Product lifecycle management.
3. Traceability and recall management.
4. Supplier relationships.

Jie et al (2010) analyse supply chain performance indicators among Australian lamb processors. The results indicate that food quality and efficiency are significant indicators of competitive advantage for lamb processors, which implies a need for improved monitoring facilities.

O'Hagan (2014) develops an assessment model of the operational and organisational structure with regard to the AMOR approach (Alliances for the Mutual Organisation of Risk oriented inspection strategies). The AMOR model comprises the formation of an alliance between suppliers and customers in the supply chain for mutual benefit. Collaboration in the alliance is realised by jointly organising inspections which are performed in a risk oriented manner. Accordingly, there are four principles underpinning the concept:

1. Inspection design
2. Tasks and responsibilities
3. Information and communication structure
4. Costs/efforts and benefits to all parties

Scott et al (2012) present the results of a quantitative survey of structured continuous improvement programs in the Canadian food sector. Companies that used continuous improvement were less likely to have product recalls than companies that did not.

Dora et al (2013a) explore the need for a user-friendly food quality management system (FQMS) customised to the requirements of small and medium-sized enterprises (SMEs) for improving product and process quality and enhancing customer satisfaction. However, the findings of this study show that none of the food SMEs involved implements FQMS in its true form. The size of the company is a significant factor with respect to quality management implementation, as medium-sized companies were more mature in FQMS implementation compared to their small and micro counterparts. The confectionery, chocolate and meat sectors are more advanced than bakery, packaged fruits and vegetables sectors, with respect to the implementation of quality management tools and techniques. The study also revealed that the most important benefits of a quality management system were reduction in cost of production and increased productivity.

Dora et al (2013b) show that the application of Lean manufacturing practices in food SMEs is still at its infancy. Food processing SMEs place more emphasis on food safety than on process improvement methods. The respondents indicated improvement in operational performance, especially with overall productivity from the application of Lean manufacturing. Skill of workforce, in-house expertise and organisational culture are critical factors for successful implementation of lean manufacturing practices.

Kovach and Cho (2014) identify four major sources of variation within agri-food processes:

1. Insufficient design margins, such as poor design machinery and operating environments.
2. Inherent variability of any manufacturing process (the five Ms – machine, method, materials, man and measurement).
3. The measurement system's inherent variability, which could cause up to twenty five percent of the problems and defects in production.
4. Variable products provided by subcontractors and vendors. The consumer blames the end manufacturer of the product they buy, even if the problem came from a manufacturer's vendor.

Ritchie et al (2011) state how the “current food trading system is geared to making money rather than feeding people well, preserving biodiversity and soil health, or mitigating climate change” (Ritchie et al 2011, 9). The problem is one of “Business as Usual” (BAU) in which we are committed to an unsustainable system (ibid.), versus the alternative “Many to Many” (M2M) approach which is devised to “maintaining and empowering a broad base of primary producers and processors to make good food – first for themselves and their families, then their communities, then for their regional markets, and then for global trade” (Ritchie et al 2011, 10). In contrasting BAU with M2M Ritchie et al (2011) suggest that as world populations become more affluent they begin to adopt a “Western diet” which contains “more meat, dairy and energy-dense foods” (ibid.). This means that more land needs to be given over to the farming of animals and that additional land is required in order to grow grains to feed the animals irrespective of the grain necessary to feed populations. By contrast, M2M seeks to define production more widely. “Useful labour is seen as a benefit, not just a cost: animal welfare is seen as an outcome in itself, not a production variable; sustaining and enhancing biodiversity and soil health is central to agriculture, not at the margin (of the field, and of attention). Farming is a social activity, with its primary purpose to feed local people well, and the production of commodities for export seen as secondary” (ibid.).

From here Ritchie et al (2011) propose six recommendations for local food initiatives:

1. Support “grow your own” and community growing projects (Ritchie et al 2011, 46);
2. Build capacity for mutual food initiatives (Ritchie et al 2011, 47);
3. Support local food systems through joint public procurement (Ritchie et al 2011, 48);

4. Support local food training and exercise (Ritchie et al 2011, 49);
5. Recycle soil nutrients (Ritchie et al 2011, 50);
6. Help farmers produce and market more sustainable food (Ritchie et al 2011, 52).

The report closes with "Implications for a National Food Policy" to infer how the M2M model could be developed nationally (Ritchie et al 2011, 53).

Jarzebowski et al (2013) suggest that the efficiency of agri-food companies within the food supply chain can be improved by exploring the relationships between each of the variables within the chain. This is based upon the use of Cobb-Douglas and trans-logarithmic functions to illustrate the effect of external variables upon the economic performance of companies.

De Giovani et al (2013) discuss the problem of unexpected demand – that is, a specific kind of demand that is not anticipated or predicted and for which the application of all forecasting methods is totally ineffective. In this respect, companies frequently overlook a managerial orientation which facilitates performing under unexpected events and properly addressing those events. The paper develops the concept of Reactivity in which unexpected demand is anticipated. Reactivity is approached first by qualitative analysis and secondly by quantitative analysis. During the qualitative analysis the authors put forward a twelve-point hypothesis:

1. The use of standardised components positively influences Reactivity.
2. The implementation of a centralised logistics system positively influences Reactivity.
3. The implementation of an integrated information system positively influences Reactivity.

4. A large production capacity positively influences Reactivity.
5. Workers' availability positively influences Reactivity.
6. A high supplier turnover negatively influences Reactivity.
7. A short distance between customers and suppliers positively influences Reactivity.
8. A higher customer impact positively influences Reactivity.
9. Product innovations negatively influence Reactivity.
10. Reactivity positively influences sales.
11. Reactivity positively influences return on investments.
12. Reactivity positively influences return on assets.

From these twelve points it is then possible to construct a quantitative empirical analysis model identify the best practices which contribute to a Reactivity orientation as well as the economic benefits that Reactivity provides through its global and partial effects.

It is then clear that there are a wide variety of issues within the CFSC which need to be identified before a monitoring platform can be implemented.

1.5. Research Questions

The literature search was conducted in accordance with the following research questions:

1. What are the key issues involved within the chilled food supply chain (CFSC)?
2. How do we implement a philosophy of continuous improvement as a means of reducing waste or variation within the CFSC?
3. How do we anticipate the main areas of uncertainty so that the optimum amount of waste or variation can be reduced within the CFSC?

4. How do we measure and improve the performance of the existing supply chain model?
5. How does uncertain customer demand affect the global food losses and waste (FLW) issue, and what practices can be implemented to reduce or manage it?
6. What are some of the issues involved with information sharing between suppliers and retailers?

1.6. Thesis Outline

Chapter One provides an overall structure, overview and outline of the thesis.

Chapter Two provides an overview of the key issues identified within the CFSC.

Chapter Three discusses how a Lean philosophy of continuous improvement can be implemented into the CFSC.

Chapter Four discusses ways of managing uncertainty with the CFSC.

Chapter Five discusses ways to measure and improve the performance of the existing supply chain model.

Chapter Six discusses the impact of uncertain customer demand upon the global FLW issue, and what practices can be implemented to reduce or manage it. This chapter will also discuss local food initiatives, the rise of fast food, the impact of many recent food scandals and the need for improved methods of traceability, what we can learn from the Slow Food movement, as well as how we can learn from the rise of coffee shop chains and the need to sell ambience and social positioning as a part of the gastronomic experience.

Chapter Seven outlines the methodology which will be used. It proposes that a mixed strategy will be required, given that the CFSC contains both qualitative and quantitative issues. The hypotheses are then better informed by the literature search.

Chapter Eight is concerned with compiling and/or developing existing models for each of the issues identified into a form that can be expressed as a data envelopment analysis (DEA) model, or which already exist as hybrid models based on a combination of DEA and the Analytic Hierarchy Process (AHP).

Chapter Nine presents an overview of the information sharing problem between retailers and suppliers. Hence, this chapter is concerned with the game theory models underpinning relationships between retailers and suppliers, the types of games available, their equilibria, the issues involved with information sharing (i.e. why it favours retailers over suppliers), and how companies can effectively improve their supply chain strategy by implementing an adaptive goal setting algorithm.

Chapter Ten – Concluding Remarks and Further Work. This chapter provides a review of the research questions, the hypotheses and a hierarchy of the models developed and compiled ready for a full software implementation.

Bibliography

1.7. Definitions

Within the literature definitions given are often inconsistent with each other. Therefore, a number of terms and concepts will need to be defined so that the thesis is self-consistent. These include:

1. Supply chain management;
2. The supply chain network;
3. The chilled food supply chain;
4. The Chilled Food Supply Network;

Other terms will be defined and explained as necessary as the study unfolds.

1.7.1. Supply Chain Management (SCM)

Here SCM is defined as “an integrative, proactive approach to manage the total flow of a distribution channel (including procurement) to the ultimate customer” (Matthyssens and Van den Bulte 1994). Accordingly, integrative implies close working relationships between companies and the stages of the supply chain model, which is consistent with the approach taken during this study.

1.7.2. The Supply Chain Network

A supply chain is represented as a network of nodes, which signify the various stages products and services must pass from supplier to customer. From figure 1 it can be seen that the main function of the supply chain is to pass material from the suppliers to the customer via manufacturers, distributers and retailers.

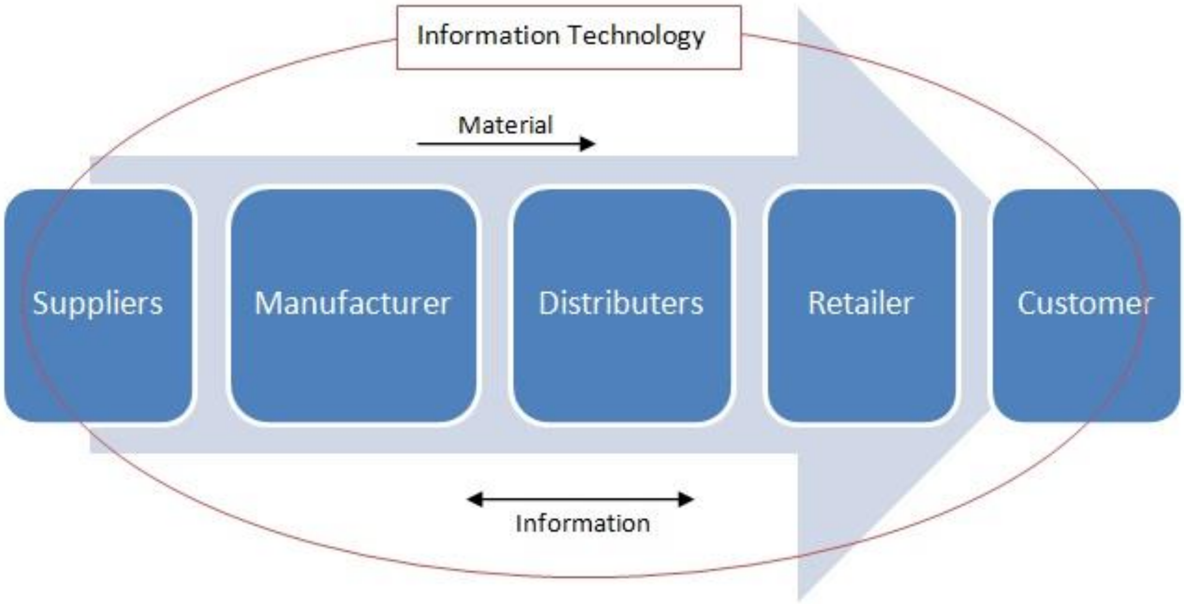

Figure 1.2. The stages of the supply chain network.

It is also clear that for the supply chain to be effective, information must pass from the customer to the retailer, the distributors, the manufacturers and the suppliers. Without demand for a specific product or service the supply chain is ineffective.

1.7.3. The Chilled Food Supply Chain (CFSC)

By definition, supply chains do not exist in isolation from each other. They are based on a complex sequence of interrelations and interactions between material and information systems (Stone 2011, 14). In this respect the CFSC is unique, in that it derives from the agri-food chain and the cold chain, as illustrated in figure 1.3. Indeed, the agri-food supply chain itself is a combination of the agricultural supply chain and the food supply chain for similar reasons.

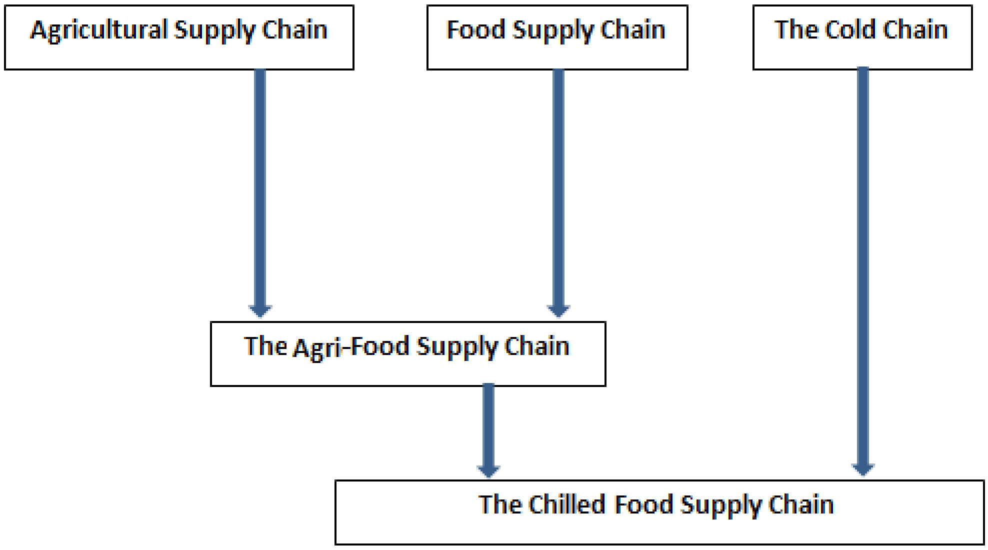

Figure 1.3. Diagram to illustrate the derivation of the CFSC.

It then follows we cannot consider the chilled food chain in complete isolation without some knowledge of the wider interactions taking place within the agri-food chain and the cold chain.

1.7.3.1. The Agri-Food Supply Chain

The agri-food chain itself is a contraction of “agriculture” and “food” to infer a total overview of the stages and processes involved “from farm to fork” or “from gate to plate”. At its core are farmers, processors/manufacturers, retailers and consumers. Around these core groups are hauliers, wholesalers, packaging suppliers, government agencies and nongovernmental organisations. Figure 1.4. illustrates the structure of the agri-food supply chain:

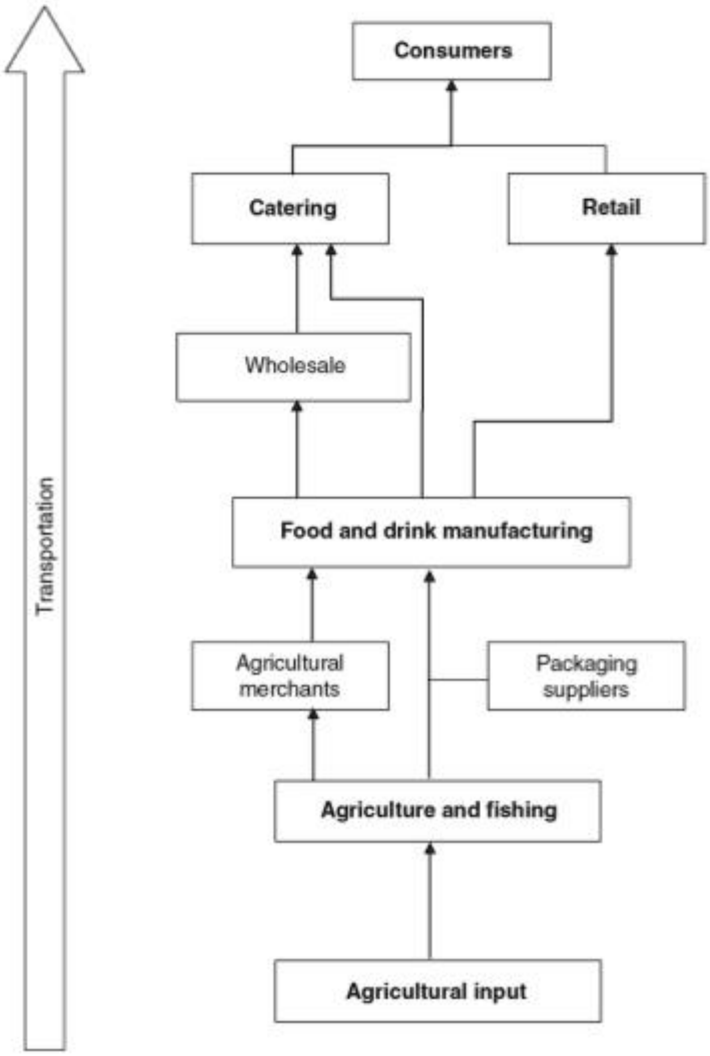

Figure 1.4. The agri-food supply chain, based on the diagram as given by (Mena and Stevens 2010, 4).

As can be seen from the diagram, the agri-food chain is composed of a number of sub-chains, including agriculture, agriculture and fishing, food and drink manufacture, which lead to wholesalers, caterers, retailers and consumers. The one common factor running throughout the agri-food chain is transportation, or how to move goods from one stage of the supply chain to the next.

1.7.3.2. The Cold Chain

The cold chain is a temperature controlled supply chain, as illustrated in figure 1.6. below:

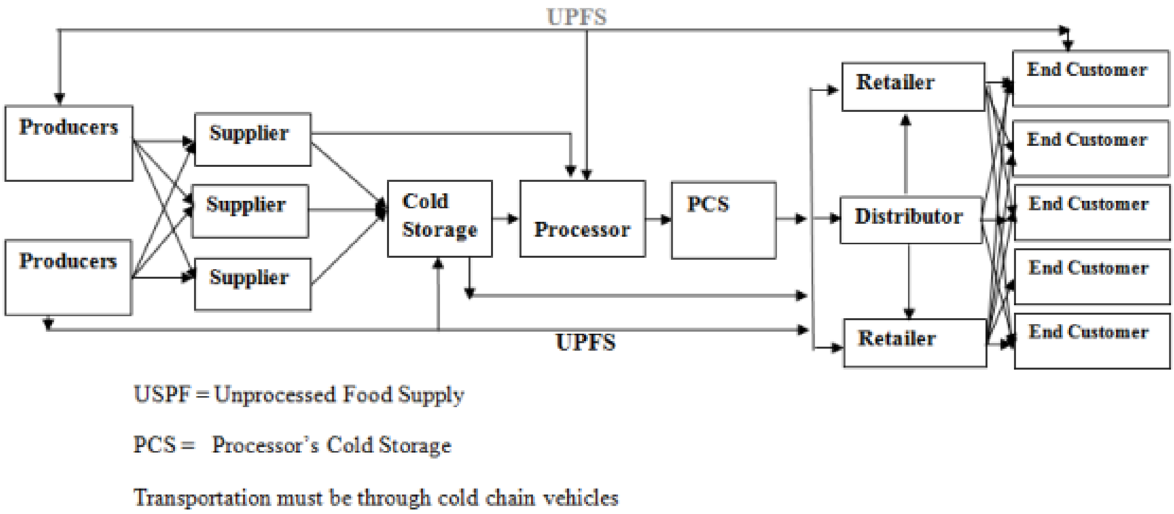

Figure 1.5. Diagram of the cold chain based on (Shashi and Singh 2015, 198).

However, the CFSC is only one facet of the cold chain, which otherwise includes products such as pharmaceuticals, chemicals and blood products (i.e. for hospitals), although many authors use the terms "cold chain" and "chilled food supply chain" interchangeably.

1.7.3.3. The Main Segments of the Chilled Food Supply Chain

Kitinoja (2013) has identified the main segments of the CFSC:

1. Packaging and cooling of fresh food products;
2. Freezing of certain processed foods;
3. Long or short term cold storage of chilled or frozen foods;
4. Cold transport and the temporary storage of chilled or frozen foods under temperature controlled conditions;
5. Marketing of chilled or frozen foods at wholesale markets, retail markets and food service operations (Kitinoja 2013, 2).

1.8. Limitations and Key Assumptions

There is a two-fold focus upon this thesis: firstly, the identification of the key issues affecting the CFSC; secondly, compiling the most appropriate models and algorithms available to enable effective management of these issues. Clearly, the total eradication of such problems would be well beyond the scope of this study. In addition, many of the models presented concentrate upon the relationships between suppliers and retailers, rather than between manufacturers, suppliers and retailers. This is because it is assumed that fruit, vegetables, dairy produce, eggs, etc. are produced by farmers and growers. Hence, there is parity between suppliers and manufacturers within the agri-food chain.

1.9. Conclusions

This chapter is intended to provide an overall introduction to the project as well as giving reasons for why the project is necessary. However, the main focus of the project will be upon identifying and developing algorithms, which can be later integrated into an Industry

4.0 management system that is intended to improve process monitoring across the chilled food supply chain and therefore to effectively reduce and/or manage the overall level of food losses and waste (FLW) that is produced.

Chapter Two – Key Issues within the Chilled Food Supply Chain

2.1. Introduction

This chapter will provide an overview of the key issues identified within the chilled food supply chain (CFSC). It will follow the structure as given in Figure 2.1 below:

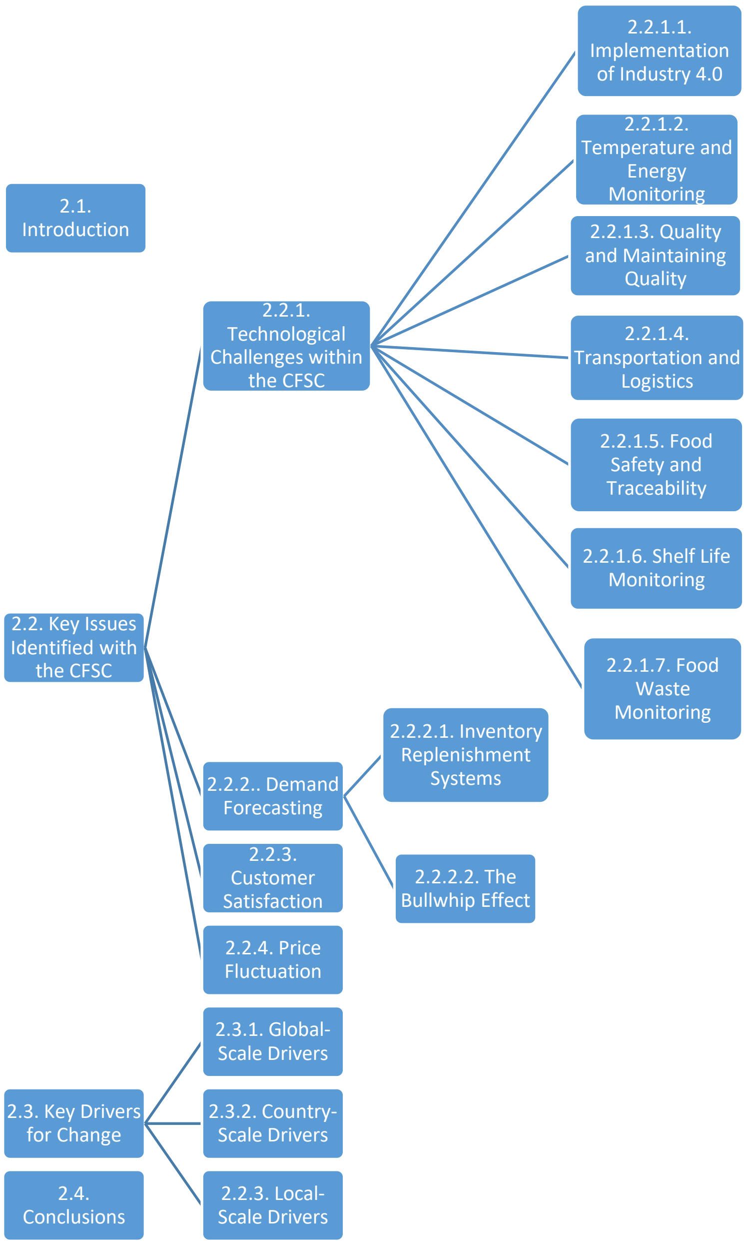

Figure 2.1. to illustrate the structure of Chapter Two.

2.2. Key Issues Identified within the CFSC

The following key issues have been identified as being affected by Industry 4.0:

1. Technological challenges within the CFSC;
2. Shelf life monitoring;
3. Food waste monitoring;
4. Demand forecasting;
5. Customer satisfaction;
6. Price fluctuation.

These will be discussed below.

2.2.1. Technological Challenges within the CFSC

Here “technological challenges” is taken to refer to the need for food companies to keep up to date with the latest advances in technology in order to maintain a competitive business edge. Technological challenges include:

a. Implementation of Industry 4.0;
b. Temperature and energy monitoring;
c. Quality and maintaining quality;
d. Transportation and logistics;
e. Food safety and traceability;
f. Shelf Life Monitoring;
g. Food Waste Monitoring.

Each of these topics will be briefly discussed below:

2.2.1.1. Implementation of Industry 4.0

Herman et al (2015) state that a "generally accepted definition" of Industry 4.0 has not yet been published (Herman et al 2015, 3). However, Herman et al (2015) also provide some context for Industry 4.0 as the "fourth Industrial Revolution", with:

1. The first "revolution" referring to the "introduction of mechanical production facilities starting in the second half of the 18th century and being intensified throughout the entire 19th century";
2. The second revolution referring to the "electrification and the division of labour" from the 1870's onwards;
3. The third revolution referring to the "digital revolution" of the 1970's when "advanced electronics and information technology developed further the automation of production processes" (Herman et al 2015, 5).

Herman et al (2015) also state that fascination for Industry 4.0 is two-fold: firstly, because this "industrial revolution is predicted a priori, not observed ex-post" (Herman et al 2015, 3; Drath 2014, 2) and secondly because it "promises substantially increased operational effectiveness as well as the development of entirely new business models, services, and products" (Herman et al 2015, 3). From here, Herman et al (2015) suggest that Industry 4.0 is based on six design principles, which are:

1. Interoperability – this means that the cyber-physical systems (CPS) involved must be able to communicate with each other.

2. Virtualisation – this means that CPS are able to monitor processes. Accordingly, any sensor data needs to be effectively connected to its virtual simulation.
3. Decentralisation – accordingly, the advent of embedded computers and RFID tags means that processes can function independently without the need for a centralised hub. However, due to the need for quality assurance and traceability, it is important that a record of activities performed within the system is monitored.
4. Real-time capability – if at any given time a machine fails, it is necessary that the system is capable of rerouting and reconfiguring itself in order to complete its assigned task.
5. Service orientation – this means that product specific process operation can be configured in relation to a set of customer specific requirements provided.
6. Modularity – this means that modules can be added or subtracted as the system develops and evolves.

By comparison, Lee et al (2014) suggest the following five issues will need to be resolved in order for Industry 4.0 to be fully realised:

1. Manager and Operation Interaction – accordingly, “managers design” whilst “operators control” machine logistics.
2. Machine Fleet – accordingly, machines are maintained individually rather than they are considered as a “fleet” of machines. Hence, there is a missed opportunity to compare the data from similar machines which have been designated similar tasks.
3. Product and Process Quality – product and process quality can be assessed in relation to machine health via “backward reasoning algorithms” (Lee et al 2014, 4). This also includes the idea the supply chain model can be reconfigured should a machine fail, or should there be a disruption within the supply chain network. Hence,

closer monitoring of product and process quality may contribute to this kind of improvement.

4. Big Data and Cloud – whilst data management and distribution of Big Data is important, diagnostic techniques to fully manage cloud computing failures still need to be developed.
5. Sensor and Controller Network – accordingly, sensor failure and degradation may produce inaccurate readings of important data. Hence, there is a need to develop improved diagnostic procedures in order to overcome these kinds of problems.

Hence, the successful implementation of an Industry 4.0 system begins with the application of semi-intelligent devices for close monitoring, diagnostic procedures, benchmarking and improving upon current targets. We must then consider what we mean by "semi-intelligent".

Atzori et al (2010) suggest that Industry 4.0 needs to be considered as an intersection of "Things" (i.e. devices), "Semantics" (i.e. how to represent, store, interconnect, search and organise information) and "Internet" (i.e. the protocols upon which the system is to run). This implies that "semi-intelligence" arises from this intersection, which in itself implies that Industry 4.0 can only be achieved when we have integrated high-level (and ideally "natural") language processing into our technology.

Li et al (2012) suggest that the combination of wireless networks such as LANs (Local Area Networks) and WLANs (Wireless Local Area Networks), as well as WMNs (Wireless Mesh Networks) and WSNs (Wireless Sensor Networks), Bluetooth-based Piconet, RFID-based information systems provide opportunities to offer greater visibility within business processes and activities (Li et al 2012, 165), whilst there has been a growing trend for businesses to adopt Enterprise Information Systems (EIS) (ibid.). However, Li et al (2012) also suggest that with the wider acceptance of Cloud computing there is a pressing need to integrate wireless networks and EIS in order to improve supply chain performance (Li et al 2012, 167). Hence, whilst Li et al (2012) use the acronym "IEIS" for Integrated Enterprise Information System, the more appropriate acronym would be "WEIS" for Wireless Enterprise Information System. Hence, the concept of a WEIS supply chain (i.e. as a pun upon "Weiss", "wies" or "Wise") also informs Lee et al (2014)'s discussion of the transition from "regular machines" into "self-aware and self-learning" machines. In other words, a WEIS supply chain improves with technological innovation within "Things", "Semantics" and "Internet", even if the mechanism for its adaptation has not yet been fully-realised.

Sinderen and Almeida (2011) discuss the concept of Enterprise Architecture (EA) as a tool for "understanding, designing and evolving an enterprise" (Sinderen and Almeida 2011, 1). In anticipating Industry 4.0 Sinderen and Almeida (2011) suggest that the EA concept will itself expand into "a business services ecosystem, in which demand and supply can be brought together at a global scale and partnerships can be much more dynamic (Sinderen and Almeida 2011, 5). However, such expansion also raises "the issue of trust, privacy and security" alongside how the data is collected and managed, technically and organisationally (ibid.).

Hence, the development of a true WEIS supply chain network will have impact upon the other four technological challenges identified: temperature and energy monitoring; quality and maintaining quality; transportation and logistics; food safety and traceability.

2.2.1.2. Temperature and Energy Monitoring

The main shelf-life determining post-processing parameter in the CFSC is temperature (Gogou et al 2015, 109). Niranjan and Kulkarni (2012) discuss the overall cost associated with different cold chain multi-echelon networks under stochastic demand and probabilistic information loss/accuracy conditions. Accordingly, the cold chain may be chilled, frozen or cryogenic. Whilst the chilled food chain is unlikely to reach cryogenic temperatures (i.e. below $-160°C$), the need for control, continuous monitoring, documentation and temperature recording across the cold chain is of vital importance (ibid.).

Energy plays a strategic role along food supply chains, since it is fundamental to guarantee quality and influential in the determination of economic values. Zanoni and Zavanella (2012) discuss a four-node supply chain model: harvest – producer – distribution centre – retailers. Accordingly, the most relevant parameter linking quality and energy is the temperature set to preserve food. The lower the temperature the higher the energy required along the chain and the longer the food quality is preserved (Zanoni and Zavanella 2012, 732).

Whilst temperature plays a primary role in quality degradation, temperature along the cold chain cannot always be considered to be uniform. Therefore, the total quality decrease may be modelled as a summation of quality decreases along the supply chain. Accordingly, a Weibull-power law model can be used to describe the isothermal degradation of food quality, depending on storage temperature and time (Peleg et al 2002).

Rong et al (2011) discuss the physics of the cooling process necessary to reach different temperatures and to maintain them. This is achieved by comparing the coefficients of performance of the cooling phases required.

2.2.1.3. Quality and Maintaining Quality

Ilbery and Kneafsey (2000) claim that quality is defined in terms of product specification and attraction despite regulatory frameworks and consumer concerns, social certification schemes or association with region of origin. Food quality, however defined by producers, is essentially self-regulated and constructed within the context of maintaining stable relationships between producers and buyers.

Rodgers (2005) addresses the subject areas identified by QAAHE (2000): food safety management, food quality management and product development; equipment and facility layout/design; operational planning and modelling; as well as market and consumer related aspects (Rodgers 2005, 302). Rodgers (2005) identify the main types of research and develops conceptual links between the scientific fundamentals of food service operations and industry practices.

Rong et al (2011) provide a methodology to model food quality degradation in such a way that it can be integrated in a mixed integer linear programming model used for production and distribution planning. The model is applied to a case study and can be used to design and operate food distribution systems, using both food quality and cost criteria.

2.2.1.4. Transportation and Logistics

Clearly, the less time food spends in transit the less time it has to degrade and the less energy is required in order to maintain temperature protocols. The most studied transportation problem in this area is the capacitated vehicle routing problem (CVRP). This consists of the distribution of goods from a single depot to a given set of customers or nodes within the supply chain network (Irnich, et al 2014, 3). The CVRP is classified according to the following issues:

1. The network structure (i.e. air, sea or land);

2. The type of transportation requests;
3. The constraints that affect each route individually;
4. The fleet composition and location;
5. The inter-route constraints;
6. Optimisation objectives (Irnich, et al 2014, 9).

Modelling approaches are generally divided into two categories:

1. Models which consider the environment within the transport unit (James et al 2006, 949);
2. Models which concentrate on the temperature of the product (ibid.).

Some models combine the two approaches and are concerned with the temporal aspects of food transportation, i.e. fluctuating ambient conditions, door openings, product removal/loading (ibid.). Other models are concerned with the effects of transportation effects upon microbial growth rates (ibid.).

Vignault et al (2008) lists some of the common reasons for losses and wastage within the transportation stage of the CFSC, which include:

1. Temperature – given that fresh fruit and vegetables remain alive by respiration, temperature is the primary factor controlling respiration rate (Vignault et al 2008, 3). Similarly, freeze damage can be caused by keeping products below their recommended temperatures during transit (ibid.), whilst exposing frozen products to temperatures above $0^{\circ}C$ for extended periods of time will lead to products being wasted.

2. Humidity and water loss – most fruit and vegetables need to be kept at a 90% to 95% relative humidity, whilst some products like bulb onions, garlic, squashes need to be kept below 70% relative humidity (ibid.).
3. Atmospheric composition – CO_2 levels need to be kept at 0.3% in a tightly-sealed container to prevent a build-up in CO_2 levels (Vignault et al 2008, 4).
4. Mixed loads – given that many chilled food products have different storage requirements during transport, it follows that mixed loads can potentially lead to the necessary storage atmospheres being compromised (Vignault et al 2008, 5).
5. Physical injury – packaging, package management and correct product storage can all be used to prevent physical injury to fresh produce that is caused by vibration, compression and impact (Vignault et al 2008, 6).

Other considerations include the approaches necessary to maintain quality during transport, which include the cooling requirements (Vignault et al 2008, 7), refrigeration systems and air circulation systems (Vignault et al 2008, 9), but also the physical structural considerations of the transport system, which include the floor and ceiling of the vehicle, ventilation systems, the doors and walls, insulation systems, and a return air bulkhead, which provides a pathway for air to return to the evaporator and isolates the load from the front wall of the vehicle (Vignault et al 2008, 14).

2.2.1.5. Food Safety and Traceability

According to Moe (1998) and Dupuy et al (2005):

> Traceability is the ability to track a product batch and its history through the whole, or part, of a production chain from harvest through transport, storage, processing, distribution and sales (hereafter called chain traceability) or internally in one of the steps in the chain for example the production step (hereafter called internal traceability) (Moe 1998; Dupuy et al 2005, 334).

This definition implies that models can be constructed for “chain traceability” and “internal traceability”. Dupuy et al (2005) add two further definitions which are beneficial towards the modelling process:

1. Tracing – the ability to find origin and characteristics of a product from one or several given criteria in every point of the supply chain, but is particularly associated with finding the source of quality control issues;
2. Tracking – the ability to find the localisation of products from one or several given criteria in every point of the supply chain, but is particularly associated with product recall.

Understanding the difference between tracing and tracking is then highly significant, as suggested by the literature.

Aung and Chang (2013) discuss the need for faster response times within the food industry to deal with food scandals and food incidents, which suggests that tracing and tracking models have been grossly inefficient. These kinds of incidents have been brought to public attention by the meat adulteration scandal of 2013, in which foods advertised as containing beef in fact contained as much as 100% horse meat (Lawrence 2013). Accordingly, some forms of meat production had “more than 450 critical control points” between the farmer and end consumer within the supply chain (ibid.).

Luning et al (2006) list a number of factors related to food safety. The main considerations include: the agri-food production chain, biological hazards, chemical hazards, physical hazards, Quality Assurance Systems and food Safety, HACCP considerations and miscellaneous hazards. Hence, food safety can only be assured via improved tracing and tracking protocols, which in turn implies that models for “chain traceability” and “internal traceability” might be inaccurate.

2.2.1.6. Shelf Life Monitoring

Freshness is one of the most important aspects of the chilled food chain, which means that products can only be stored for a short time before they deteriorate (Zhang et al 2009). In the UK a system of date coding is used to determine the shelf life of food products, which is defined by as the time during which the food product will:

1. Remain safe;
2. Be certain to retain its desired sensory, chemical, physical and microbiological characteristics;
3. Comply with any label declaration of nutritional data, when stored under the recommended conditions (Kilcast and Sabraniam 2000, 2).

The mathematical modelling of food shelf life prediction is based on knowledge of food spoilage mechanisms (Koutsoumanis 2001, 1821; Koutsoumanis and Nychas 2001). For microbiologically perishable food products, a “use by” date is determined (Kilcast and Sabraniam 2000, 1). For food products with a shelf life of eighteen months or more a “best before” date is determined (ibid.).

A number of studies have been made into microbiological growth rates at fluctuating temperatures (Baranyi et al 1995; Fu et al 1991; Li and Torres 1993; Stratford 1999; Zweitering et al 1994). Of these Zweitering et al (1994) demonstrated that temperature changes around the minimum of growth showed very large deviations from the model. This means that temperature variations can greatly affect the shelf life of a chilled food product.

2.2.1.7. Food Waste Monitoring

Food waste is considered differently from most other commodity waste since it is biological material subject to degradation (Parfitt et al 2010). Additional moral and economic dimensions also include:

1. Edible material intended for human consumption that is lost, degraded or discarded at any stage within the FSC;
2. Edible material that is fed to animals or is a by-product of food processing diverted away from human food;
3. The problem of over-nutrition, that is the difference between the energy value of consumed food per capita and the energy value of food needed per capita (ibid.).

Of these three the first two dimensions are considered the most important, whilst the third can only be measured if the nutritional value of the food is known.

Mena et al (2014) propose following eight propositions regarding food waste:

1. The focus on local waste reduction enhances internal performance at the expense of the supply network, contributing to inaccurate forecasting by food producers and

retailers, causing a greater network loss of value and increase in waste (Mena et al 2014, 152).

2. Improved supply-chain wide transparency of demand information upstream in the supply network versus a focus on only internal requirements can reduce supply-chain wide food waste (ibid.).

3. An internal focus on maximizing profit and lack of transparency in managing promotions leads to increased food waste (Mena et al 2014, 153).

4. Internal focus and lack of demand transparency exacerbates a fear of stock-outs by suppliers and retailers, and promotes excessive safety inventory and causes excessive food waste in the supply network (ibid.).

5. An inadequate holistic process control across all stages of food supply networks causes waste (Mena et al 2014, 154).

6. Lack of discipline in maintaining cold chains causes food waste throughout supply networks (ibid.).

7. Longer shelf-life increases the window to sell and consume products, but does not necessarily reduce waste, if it is not matched by appropriate consumer education (ibid.).

8. Packaging can prevent waste by protecting products and extending their shelf-life, but superfluous use will result in unnecessary waste (Mena et al 2014, 155).

Of these eight points it is clear that point 6 is one of the main contributors to losses within the chilled food chain, which implies that better monitoring of temperature protocols is required. In addition, Consumer demand for high quality products with long shelf lives contributes to food waste because many products are shipped that are close to their “best before” dates, which means consumers are less likely to buy them (Soysal et al 2012).

2.2.2. Demand Forecasting

Demand forecasting or order management is concerned with comparing data about current orders with historical data in order to produce requirements for finished products (Shapiro 1999, 744). For operational and short-term tactical planning one of the main challenges is in managing the transition from forecasts having a high uncertainty to customer orders having much less uncertainty (ibid.). Longer-term planning therefore contains higher levels of uncertainty since it is reliant upon data and economic factors that, by nature, are prone to fluctuations in their levels of certainty. Although statistical methods, such as exponential smoothing and regression analysis have been used in demand forecasting for decades, these methods may prove inadequate when demand for a specific product is intermittent (Gutierrez et al 2007, 409).

2.2.2.1. Inventory Replenishment Systems

There are two main forms of inventory replenishment reorder systems: continuous time, fixed order, and periodic reorder (Disney et al 2015; Magee 1956; Rao 2003).

Continuous time, fixed order systems are based upon ordering the same quantity (or multiples) of the product at varying time intervals. In periodic reorder systems the amount of product varies at regular, repeating intervals. Here, the decision maker has to determine an order-up-to (OUT) level at each period.

2.2.2.2. The Bullwhip Effect

In order to give an immediate source of supply, and to buffer the production system from fluctuations in demand (Disney et al 2005, 151) a holding inventory is required in order to prevent the "bullwhip" or Forrester effect. This is where demand order variabilities in the supply chain are amplified and move further up the chain. Lee et al (1997) identify four main causes of bullwhip effect in supply chains:

1. Demand forecast updating – often based upon order history from the company's immediate customers;
2. Order batching – this refers to the phenomenon of placing orders to upstream echelons in batches (Hussein and Drake 2011, 973). It is based on two kinds:
    a. Periodic – where the company only orders product at fixed intervals, such as weekly, biweekly or even monthly. Here the company risks a spike in demand, followed by no demand for the remainder of the period.
    b. Push – where the company has orders "pushed" onto it from customers because sales are measured quarterly or annually, which can lead to order surges.

   Batching amplifies demand as it passes up the supply chain, since real demand is rounded-up to whole batch sizes for production purposes (Hussein and Drake 2011, 974). For instance, an initial demand for 10 items may become amplified to 100 items due to minimum batch size limitations (ibid.).
3. Price fluctuation – manufacturers and distributors have periodic promotions, like price discounts, coupons, rebates, etc. This can introduce variability due to "forward buying" where manufacturers and suppliers further up the supply chain are seeking the best price from lower down the supply chain;

4. Rationing and shortage gaming – this is where a product exceeds demand and the supplier is forced to ration remaining stock, hence leading to a variation within the supply chain.

In addition, the introduction of new products can lead to unpredictability in demand forecasting (Ed. Mena and Stevens 2010, 9). In turn, this can lead to overstocking or understocking, which itself leads to poor customer service (ibid.). Diversification can also lead to increasingly complex warehousing and distribution operations.

2.2.3. Customer Satisfaction

Caruana (2002) provides the following model for customer satisfaction as given in figure 2.2:

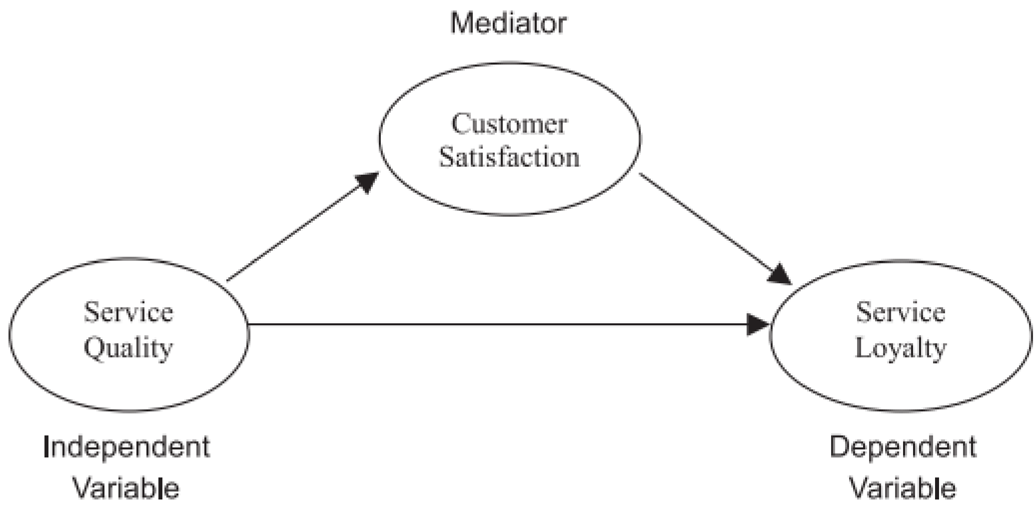

Figure 2.2. Model to illustrate the relationship between customer satisfaction, service quality and service loyalty based on Caruana (2002).

Accordingly, the level of customer satisfaction serves as a mediator between service quality (an independent variable) and service loyalty (a dependent variable). Overall satisfaction with an experience will lead to customer loyalty. This means that the quality of service is vital in order to achieve customer satisfaction and service loyalty.

However, whilst customer loyalty has long been regarded as an important goal (Reichheld and Schefter, 2000) the switching cost can also influence customer loyalty through customer satisfaction (Fornell 1992; Lee et al. 2001; Oliver 1999) and perceived value (Neal, 1999; Woodruff, 1997). Yang and Peterson (2004) investigate the interrelationships among the four constructs customer loyalty, satisfaction, switching costs, and customer value (Yang and Peterson 2004, 800). This is illustrated in figure 2.3. below:

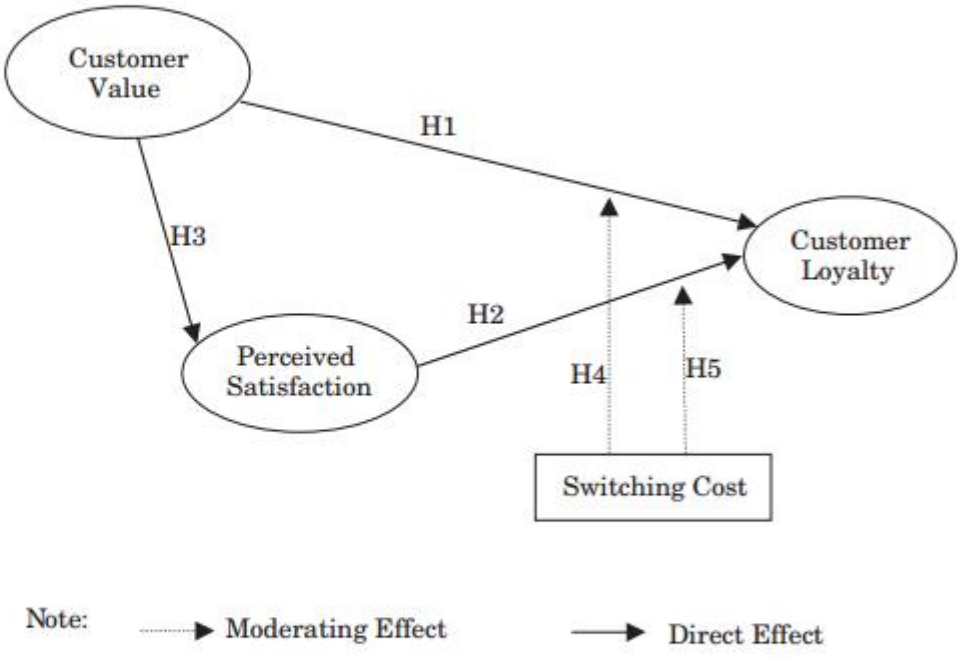

Figure 2.3. Adapted model of Yang and Peterson (2004).

Here H1, H2, H3, H4 and H5 are hypotheses which are given as follows:

H1: Customer loyalty will be positively influenced by customer-perceived value.

H2: Customer loyalty will be positively influenced by customer satisfaction.

H3: Customer satisfaction will be positively influenced by customer perceived value.

H4: The higher the level of switching costs, the greater is the likelihood that customer satisfaction will lead to greater customer loyalty.

H5: The higher the level of switching costs, the greater is the likelihood that perceived value will lead to greater customer loyalty.

However, Matzler et al (2003) discuss customer satisfaction in relation to the quality attributes a business is offering. Here satisfaction or attribute performance level is plotted against importance to the customer.

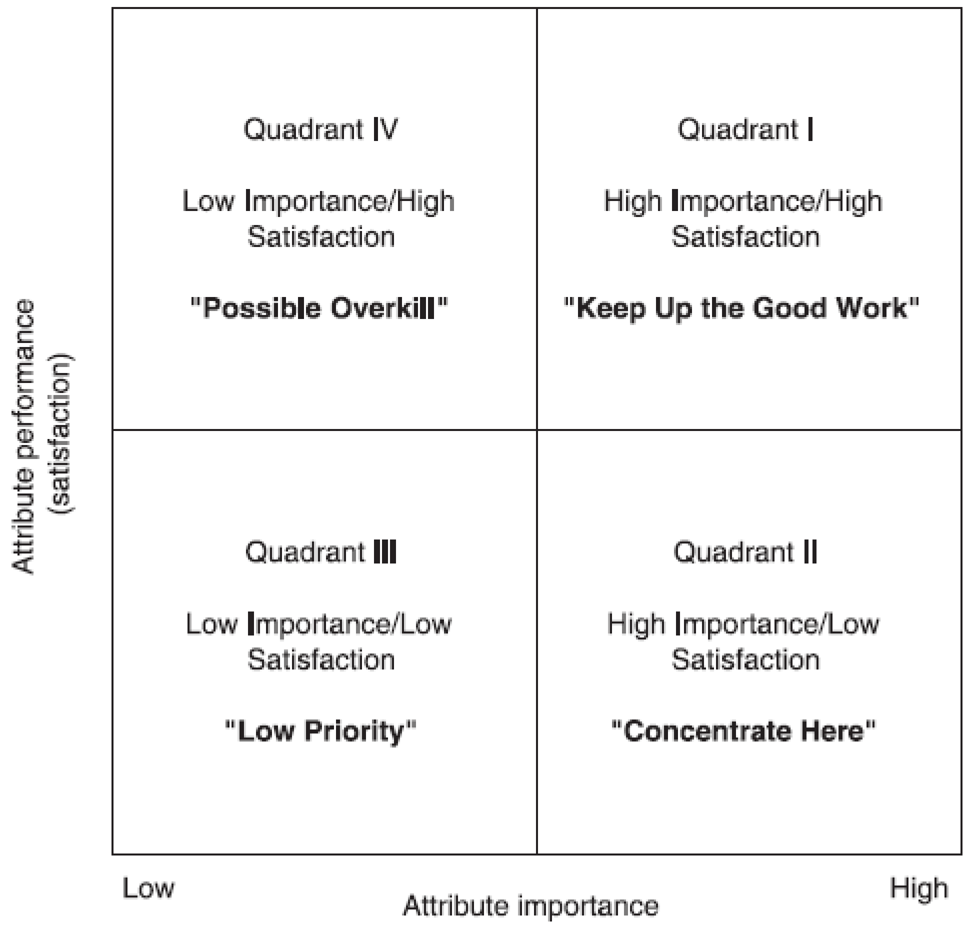

Figure 2.4. Diagram to illustrate the relationship between satisfaction and importance based on Matzler et al (2003).

Accordingly, a high importance/high satisfaction level is the ideal. However, quality attributes themselves fall into three categories: basic factors, performance factors and excitement factors (Matzler et al 2003; Anderson and Mittal 2000; Gale 1994; Johnston 1995; Matzler and Hinterhuber 1998; Matzler, Hinterhuber Bailom and Sauerwein 1996; Oliver 1997).

Basic factors, or dissatisfiers, are the factors customers have come to expect as standard, but which lead to dissatisfaction when they are not met. Yet basic factors do not lead to satisfaction if they are fulfilled.

Excitement factors, or satisfiers, increase customer satisfaction but they do not cause dissatisfaction if they are not fulfilled.

Performance factors lead to satisfaction if performance is high and dissatisfaction if performance is low.

The three-factor theory is represented according to figure 2.5. (Matzler et al 2003, 273; Kano 1984):

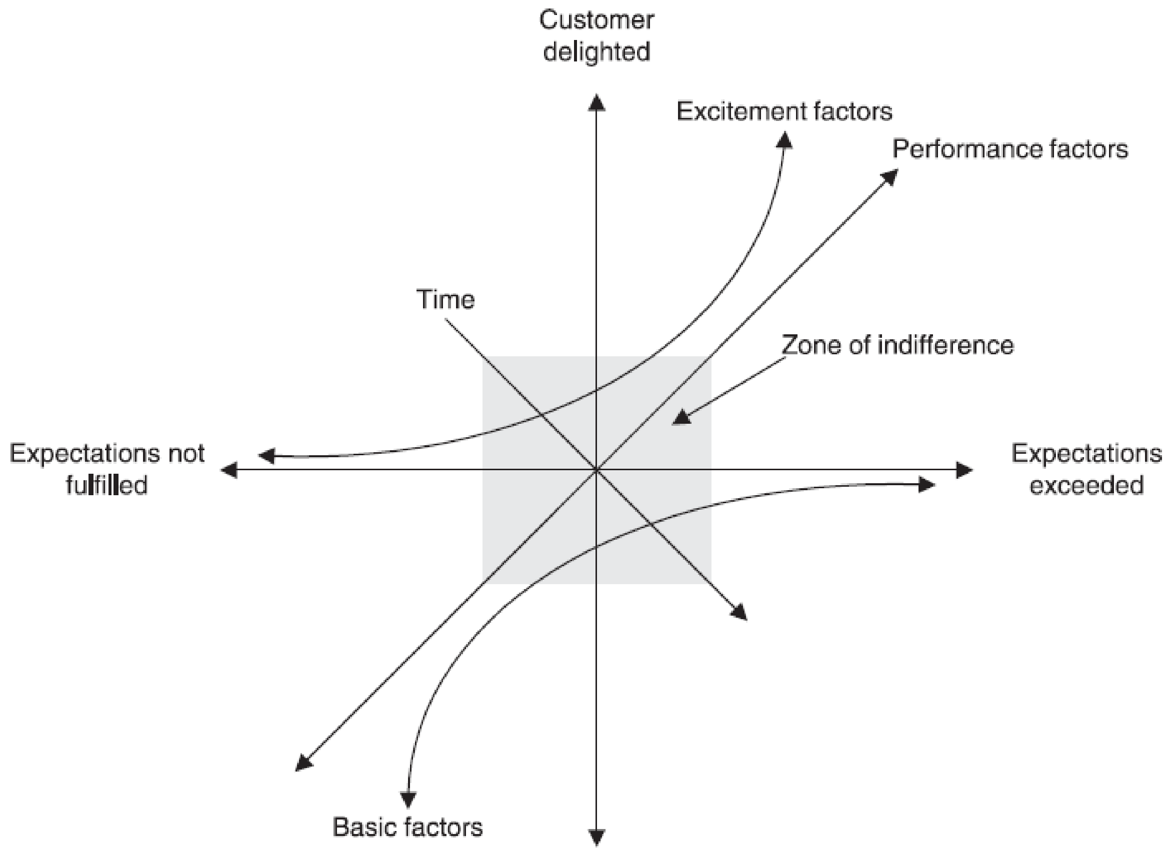

Figure 2.5. Diagram to illustrate the three-factor theory of Matzler (2003) and Kano (1984).

Of interest here is the “zone of indifference” which implies the existence of a threshold by which basic factors, performance factors and excitement factors are satisfied or unsatisfied. It follows that since the business model is subject to change with increasing competition, the threshold itself must be subject to change.

2.2.4. Price Fluctuations

Everyday low pricing (EDLP) is the policy by which each customer profits from promotions by buying more products that it needs and by buying nothing when the promotion ends because it has enough products in its inventory (Moyaux et al 2007, 2). However, the main issue with EDLP is that the quest for the lowest possible price puts stress on the supply chain which may reduce profits (Butman 2002, 31).

2.3. Key Drivers for Change

Drivers for change are any natural-induced or human-induced factors that directly or indirectly brings about change. At the most extreme range of uncertainty *force majeure* issues, such as “natural disasters, epidemics, terrorist attacks, etc.” (Hameri and Hintsa 2009, 748).

However, in more predictable terms Kearney (2010) suggests that the agri-food industry is being motivated by the global nutrition transition, i.e. a global convergence upon the “Westernised diet” which incorporates an increased intake of meat, fat, processed food, sugar and salt (Kearney 2010, 2801). Accordingly, the two main drivers of this global convergence are socio-economic factors and supply chain factors. This is illustrated in figure 2.6 below.

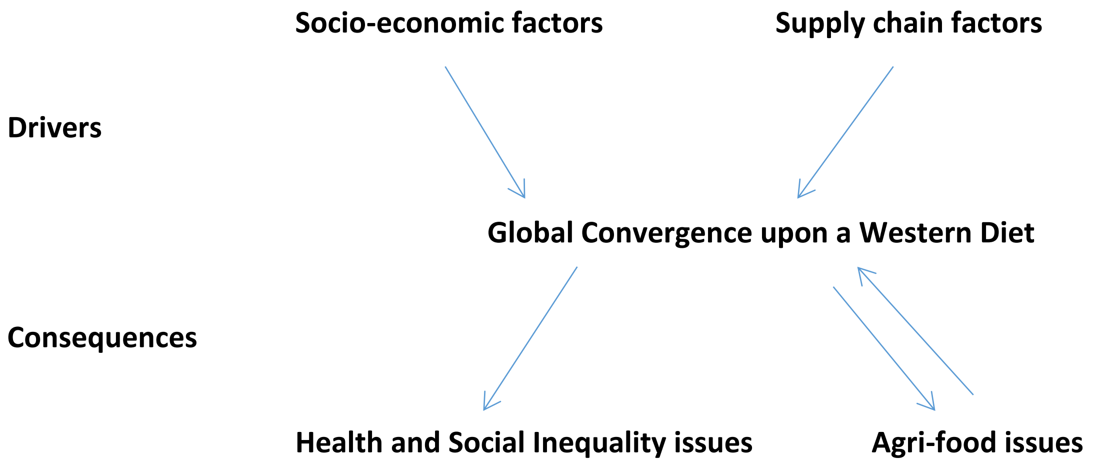

Figure 2.6. Diagram to illustrate the interrelationships between the key drivers for change, the convergence upon a Western diet and the consequences it implies for health, social inequality and agri-food issues.

However, as a consequence of the global nutrition transition there is an increase in the number of health and social inequality issues, whilst the adoption of a Western diet greatly affects the overall planning and management of the agri-food chain.

With these issues in mind key drivers for change are considered on three scales: global-scale drivers, country-scale drivers and local-scale drivers.

2.3.1. Global-scale Drivers (Macro Level)

Global-scale drivers include: international trade and globalisation of markets (Hazell and Wood 2008, 501), low world prices (ibid.), high energy prices (Hazell and Wood 2008, 502; Choi and Krause 2006), tighter security (Choi and Krause 2006; Hameri and Hintsa 2009), OECD agricultural policies (Hazell and Wood 2008, 503).

2.3.2. Country-scale Drivers (Meso Level)

Country-scale drivers include: per capita income and urbanisation (Hazell and Wood 2008, 503), changing market chains (ibid.).

2.3.3. Local-scale Drivers (Micro Level)

Local-scale drivers include: poverty (Hazell and Wood 2008, 504), population pressure (Hazell and Wood 2008, 505), health (Hazell and Wood 2008, 506), technology design (ibid.). However technology design itself depends upon three factors:

a. Property rights (ibid.);
b. Infrastructure and market access (Hazell and Wood 2008, 507);
c. Non-farm opportunities (ibid.).

2.4. Conclusions

This chapter has identified the key issues affecting the CFSC. However, in considering the key drivers for change, we have identified that monitoring at the micro, meso, and macro scales will be necessary in order for the supply chain network to better adapt to unexpected demand.

Chapter Three – Implementing a Philosophy of Continuous Improvement

3.1. Introduction

Having identified the main issues being faced by the CFSC, we are now faced with three additional problems:

1. How to implement a philosophy of continuous improvement as a means of reducing waste or variation within the CFSC;
2. How to anticipate the main areas of uncertainty so that the optimum amount of waste or variation can be reduced within the CFSC;
3. How to measure and improve the performance of the existing supply chain model.

This chapter will discuss the first of these questions in relation to the Lean philosophy of continuous improvement. It will also discuss the related problem of implementing a "pull" based system and the "Make-to-Order" versus "Make-to-Stock" dilemma which arises from it. The structure of the chapter is given in Figure 3.1 below:

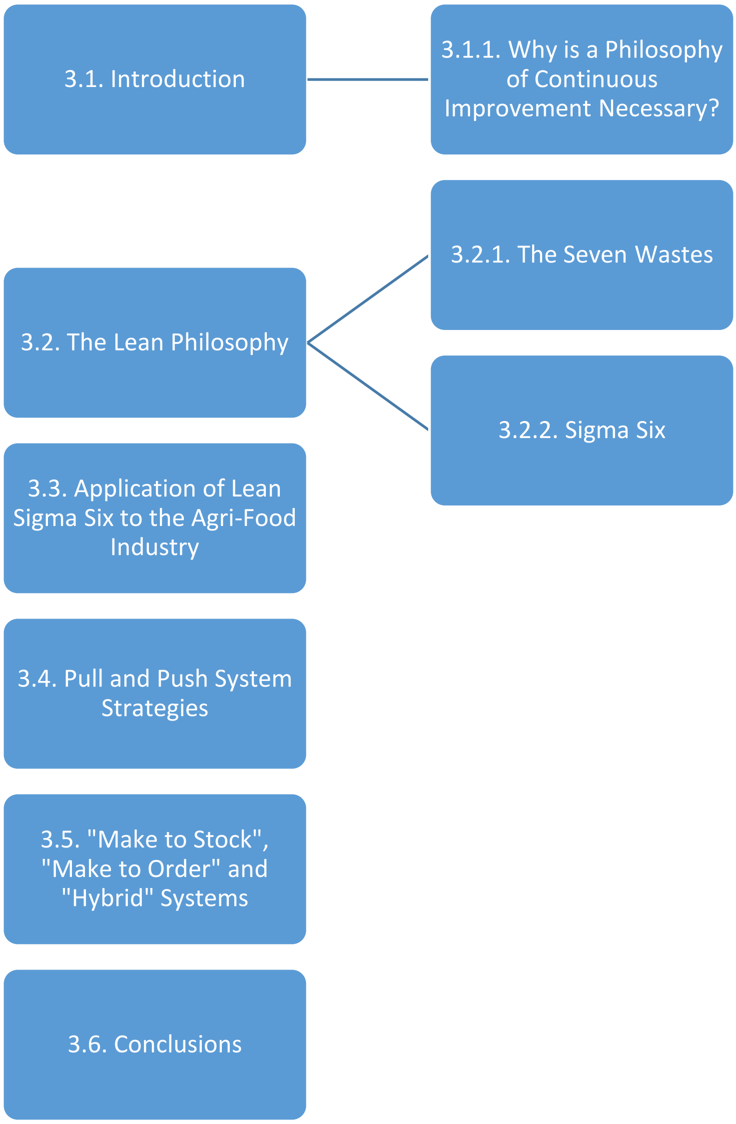

Figure 3.1. to illustrate the structure of Chapter Three.

3.1.1. Why is a Philosophy of Continuous Improvement Necessary?

Applqvist et al (2004) present a framework for supply chain decision making, including the successful integration of a product into the supply chain. This is illustrated in the Table 3.1. given below:

	Existing Product	New Product
New Supply Chain	Re-engineering	Breakthrough
Existing Supply Chain	Continuous Improvement	Design for Logistics

Table 3.1. Framework for supply chain decision making, based on the table as given by (Applqvist et al 2004).

The overall perceived risk to the company is therefore only reduced by adopting a philosophy of continuous improvement. This is because existing products must be re-engineered to cope with changes to the supply chain, or else new products are designed to accommodate existing supply chains. A completely new product and a completely new supply chain would therefore introduce the greatest uncertainty into the system by virtue of both being unproven. This follows from the idea that customers are bound to/by specific purchasing patterns. Hence, a company's performance must be based upon anticipating what these behaviour patterns are most likely to be. Hence, the most appropriate philosophy of continuous improvement to adopt is that of a Lean philosophy.

3.2. The Lean Philosophy

Lean is a philosophy of continuous improvement concerned with the reduction of waste within the value steam (Womack and Jones 2003, 15). The Toyota production system from which Lean derives classifies waste as *Muda* (i.e. non-value adding activities), *Muri* (i.e. overburden of processes) and *Mura* (i.e. unevenness, irregularity or variation) (Ohno, 1988). Lean is based on implementing the following five principles:

1. Specifying value from the point of view of the customer – i.e. only a fraction of the total time, effort and resources spent by the organisation adds value for the end customer.
2. Identify the value stream – i.e. the total set of activities across the organisation involved in delivering a product or service to the end customer. Once this has been achieved the steps which do not create value should be eliminated.
3. Flow – i.e. ensuring that the product or service “flows” to the end customer without interruption.
4. Pull – i.e. gaining an understanding of what the customer wants in terms of product or service and establishing a process to achieve it.
5. Perfection – i.e. the idealised state whereby all layers of waste within the process cycle have been removed and every asset and action adds value for the end customer.

   (Bicheno and Holweg 2004, 10, 11; Shaked 2014, 61, 62).

It should also be noted that an absolute state of perfection (i.e. zero waste) is impossible, which means that the five principles of Lean tend towards a cyclical process of continuous improvement, which is motivated by improving the value stream and driven by the natural customer pull which emerges once the improvement process has been initiated.

3.2.1. The Seven Wastes

The theory of Seven Wastes is based on removing the non-value-adding *Muda* (Ohno, 1988):

1. Waiting, by operators and machines;
2. Transportation of materials;
3. Unnecessary or overcomplicated processes;
4. Excess stock or materials (inventory);
5. Excess movement by operators;
6. Defective products;
7. Overproduction.

Lack of awareness of the Seven Wastes results in low productivity, poor quality and increased costs.

3.2.2. Sigma Six

Sigma Six focuses on reducing variation (Furterer 2009, 11). It is based upon the Define, Measure, Analyse, Improve and Control (DMAIC) approach (ibid.). The DMAIC activities are outlined in table 3.2 below:

Define	**Measure**	**Analyse**	**Improve**	**Control**

1. Develop project charter; 2. Identify customers and stakeholders; 3. Define initial voice of the customer (VOC) and critical to satisfaction; 4. Form a team and launch the project; 5. Create project plan.	6. Define the current process; 7. Define the detailed VOC; 8. Define the voice of the process (VOP) and current performance; 9. Validate the measurement system; 10. Define the cost of poor quality (COPQ).	11. Develop cause and effect relationships; 12. Determine and validate root causes; 13. Develop process capability.	14. Identify breakthrough and select solutions; 15. Perform cost/benefit analysis; 16. Design future state; 17. Establish performance targets, project scorecard; 18. Gain approval to implement and implement; 19. Train and execute.	20. Measure results and manage change; 21. Report scorecard data and create control plan; 22. Apply Plan-Do-Check-Act (PDCA) process; 23. Identify replication opportunities; 24. Develop future plans.

Table 3.2. DMAIC activities based on the table as given by (Furterer 2009, 14).

A comparison between Lean and Sigma Six is given in table 3.3. below.

Lean	**Sigma Six**
Eliminates Waste	Eliminates Defects
Process Flow	Process Yield
Pull Systems	Capable Systems
Easy Visual Approach	Rigorous Analytical Approach

Table 3.3. Contrast between Lean and Sigma Six methodologies, based on the diagram given by www.leansigmacorporation.com

As can be seen from Table 3.3, Lean and Sigma Six are complementary strategies, which when used together form Lean Sigma Six (LSS).

3.3. Application of Lean Sigma Six to the Agri-Food Industry

Dora et al (2013) show that the application of Lean manufacturing practices in food SMEs is still at its infancy. Food processing SMEs place more emphasis on food safety than on process improvement methods. This is confirmed by van Plaggenhoef (2007) who states that due to the various food crises – e.g. BSE, dioxin, swine fever, foot-and-mouth disease, H2N1 or "bird flu" – many ethical concerns have been raised and consumers are demanding more information about the food they consume.

Powell et al (2014) suggests two reasons why LSS is of interest to the food industry:

1. It would contribute to our understanding of LSS in environments other than those of discrete manufacturers;
2. Food producers experience an array of complicating characteristics that other industries may not encounter, such as perishability, seasonality and high demand uncertainty.

However, LSS has been criticised in the case when there are too many distinctive customer requirements, or when there are more variations in the production line than it can cope with (Tapping et al 2002; Sathiyabama and Dasan 2013).

In addition, Cox and Chicksand (2005) suggest that the inter-organisational aspects of Lean may not be easy to apply in practice, nor appropriate, for many participants. For some participants – especially multiple retailers – the adoption of Lean principles may lead to a positive outcome with stable and/or increasing profitability. However, for the majority of participants in these industry supply chains the adoption of Lean principles may result in a high level of dependency on buyers as well as low or declining levels of profitability.

Scott et al (2009) provide the following summary of problems identified within the food industry:

Business Benefits	**Program**	**Source**
Reduction in process variability;	Six Sigma;	Anthony et al (2005);
Increase in profitability;	Six Sigma;	Anthony et al (2005);
Reduction in the cost of goods sold;	Six Sigma; General continuous improvement;	Anthony et al (2005); Terziovski and Sohal (2000);
Reduction in waste and rework;	HACCP; Six Sigma;	Henson et al (1999); Keller (2001);
Increase in productivity;	Six Sigma;	Anthony et al (2005);
Reduction in set-up, cycle time and equipment downtime;	Six Sigma; Six Sigma; Six Sigma; General continuous improvement;	Anthony et al (2005); Keller (2001); Knowles et al. (2004); Terziovski and Sohal (2000);
Eliminate unnecessary process steps;	Six Sigma;	Keller (2001);
Eliminate unnecessary movement of product and/or personnel;		

		Keller (2001);
Reduction in customer complaints;	Six Sigma;	
		Anthony et al (2005);
Improved capacity;	Six Sigma;	
		Keller (2001);
Improved employee environment;	Six Sigma;	
		Henson et al (1999);
	HACCP;	Terziovski and Sohal (2000);
Improved sales;		
	General continuous improvement;	
		Anthony et al (2005);
Reduced inspection;		
	Six Sigma;	
		Anthony et al (2005);
Reduction in operational costs.		
	Six Sigma;	
		Anthony et al (2005);
		Henson et al (1999);
	Six Sigma;	
		Knowles et al. (2004);
	HACCP;	
	Six Sigma;	

Table 3.4. Problems identified within the food industry, based on (Scott et al 2009, 210).

As can be seen, one of the most significant issues within the food industry is that of variation. One such incidence of this is in the egg industry, given that hens lay eggs with inherently uncertain variations, e.g. number of eggs laid, weight, Haugh units (i.e. measure of egg protein), broken eggs, dirty eggs and so forth (Fuentes-Pila 2007, 315).

3.4. Pull and Push System Strategies

As briefly discussed above, "pull" appears as point four of the Lean five-step continuous improvement process. However, because the agri-food sector (and therefore the CFSC which derives from it) is prone significant levels of variation, as well as perishability, seasonality and high demand uncertainty, the implementation of a pure pull system within the chilled food sector will be far more complicated than those of traditional manufacturing industries such as the automotive and the semiconductor industries.

According to Hagel and Brown (2008) pull platforms are designed “to handle exceptions,” while push programs “treat exceptions as indications of failure” (Hagel and Brown 2008, 100). By this simple definition, variation, perishability, seasonality and high demand uncertainty ought to indicate failure. In turn, this raises the problem of why push systems have been traditionally favoured within the agri-food supply chain.

Nelson (2016) suggests that push-based platforms arose based on the assumption that customer demand can be accurately predicted so that strategic planning of the firm’s operations can be designed and resources can be allocated to meet that demand (Nelson 2016, 30). However, this assumption is itself based on an underlying assumption that demand is stable for it to be predictable.

By comparison, pull models exist to “exploit the opportunities created by uncertainty” (Hagel and Brown 2008, 93). Accordingly, pull works on two levels – the macro and the micro – as follows:

1. Macro level pull – organisations have to push up to a certain point and respond to final customer pull signals thereafter, with a view to pushing this point further and further upstream.

2. Micro level pull – responding to pull signals from an internal customer that may be the next process step (i.e. Kanban) or an important stage;

Ultimately, pull means sharing final customer demands all along the supply chain, such that each extension of pull reduces forecast uncertainty (Bicheno and Holweg 2004, 11).

Table 3.5. below illustrates the main differences between push-based and pull-based systems:

Push Systems	**Pull Systems**
Demand can be anticipated;	Demand is highly uncertain;
Top down design;	Emergent design;
Centralised control;	Decentralised initiative;
Procedural;	Modular;
Tightly coupled;	Loosely coupled;
Resource centric;	People centric;
Constrains resources;	Widens choices available;
Participation restricted;	Participation open;
Dictates actions people must take;	Provides tools and resources that allow people to take initiative;
Few participants;	Many diverse participants;
Treats people as passive consumers;	Treats people as networked creators;
Efficiency focus;	Innovation focus;
Limited number of major re-engineering efforts;	Rapid incremental innovation;
Zero sum rewards;	Positive sum rewards;
Extrinsic rewards dominate;	Intrinsic rewards dominate;
Market saturation at home;	Low retail concentration;
Slow growth at home;	Strong economic growth;
Adverse demography;	Pre-empt rivals;

Competitive market place;	Large population;
High cost structure at home;	High population growth;
Strict planning regulations;	Gain economies of scale;
Shareholder pressure to grow;	Relaxed regulatory environment;
Company ethos to go global;	Removal of entry barriers;
"Me too or I'll get left behind";	Suitable acquisition targets;
Financial markets encourage expansion;	Favourable cost structure;
Political instability;	Diversify to spread risk;
Leverage supplier relations;	Access to new capital;
Transfer know-how and extended core competences;	Favourable exchange rates;
	Improved international communications.

Table 3.5. A comparison between "Push" and "Pull" system methodologies, based on tables given by (Hagel and Brown 2008; Fearne et al 2001)

The tendency towards a "mostly-push" or "mostly-pull" based system will therefore greatly affect the decisions made by food retailers and manufacturers as to whether to adopt a "Make-to-Order" (MTO), "Make-to-Stock" (MTS) or a "Mixed" system strategy.

3.5. "Make-to-Order", "Make-to-Stock" and "Hybrid" Systems

MTO and MTS strategies are defined as follows:

1. MTO is the production strategy based on actual demand or customer orders. MTO products are products for which no inventory is held, which includes; products with highly irregular demand, client-specific products, tendered products, trial products,

or products with very short shelf life (Soman et al 2004). However, MTO is only efficient as a production strategy when there is enough demand for a given product.

2. By comparison, MTS is based purely on forecasting or anticipated demand. As a consequence MTS can lead to over-ordering (i.e. unnecessary wastage) or under-ordering (i.e. potentially risking the bullwhip effect).

Hence, the key issue is that of deciding which products should be MTS and which should be MTO (Williams 1984; Bemelmans 1986; Li 1992; Carr et al 1993; Sox et al 1997; Federgruen and Katalan 1994, 1999; Adan and Van der Wal 1998; Arreola-Risa and DeCroix 1998; Nguyen 1998; Carr and Duenyas 2000; Rajagopalan 2002; Soman et al 2007). Of these papers the Williams (1984) paper is considered the most important, since it assumes that lower demand items are produced in MTO and higher demand items in MTS.

Williams (1984) raises three specific research questions related to MTO and MTS, which are:

1. Which products should be stocked?
2. What special business (MTO) should be accepted?
3. How should one choose the batch sizes for MTS?

However, Soman et al (2007) suggest that pure MTO is unfeasible in food production due to the number of "relatively long, costly set-ups that are required" (Soman et al 2007, 192). The problem is in balancing the need to react to customer demand with the need to restrict costly setups and to produce economically stable, repetitive cycles. This reasoning implies that a hybrid MTO-MTS strategy is required.

The hybrid approach also means that items can be ordered based on an ascending demand pattern, such that a threshold level can be set so that lower demand products are

MTO and higher demand products are MTS (Zhang et al 2013; Zaerpour et al 2007; Soman 2002).

Rahimnia et al (2009) expand the hybrid MTO-MTS problem into five strategies in terms of increasing strength of customer pull:

1. Buy to Order (BTO) – where the stockholder decoupling point begins at the raw material supplier (strongest);
2. Make to Order (MTO) – where the stockholder decoupling point lies between the raw material supplier and the manufacturer (second strongest);
3. Assemble to Order (ATO) – where the stockholder decoupling point lies with the manufacturer (neutral);
4. Make to Stock (MTS) – where the stockholder decoupling point lies between the manufacturer and the retailer (second weakest);
5. Ship to Stock (STS) – where the stockholder decoupling point lies at the retailer (weakest);

   (Rahimnia et al 2009, 803).

This implies that a pure pull driven system would have to be a BTO model since every stage in the production is determined by the end user. However, this may not always be practical, since the presence of a customer at the time a service is produced adds to the overall level of uncertainty within the supply chain (Rahimnia et al 2009, 804), which can lead to the bullwhip effect (see section 2.2.4.2.). In addition, “customers in mass services expect low prices and at the same time, very short lead times” (ibid.). Accordingly, excessive lead times can sway customer decision as to whether or not to endorse a particular product or service.

In theory, this means that an ATO strategy is the most neutral MTO-MTS strategy to adopt. E.g. a pizza or a sandwich which is made for the customer from stock ingredients is an ATO product and not a MTO product. Hence, the key issue here is in identifying where the location of the MTO-MTS decoupling point should be. The concept of a customer order decoupling point (CODP) suggests that the typical candidates for MTO are:

1. Products that contribute little or irregular work load to the manufacturing system, e.g. export orders and tenders;
2. Items with low setup times;
3. Items with a high holding cost;
4. Customised products;
5. Highly perishable products;

   (Soman et al 2002, 11).

Yet these points are only considered valid only for single product-by-product analysis. There are a number of issues surrounding capacity co-ordination, given the firm MTO orders and anticipated demand for the MTS items:

1. How to do capacity allocation among MTO and MTS product? (ibid.)
2. Should we adopt a fixed cyclic sequencing strategy or dynamic sequencing? (ibid.)
3. What should be the length of the production cycle for products grouped into families?
4. What should be the number of runs per family per production cycle?
5. What should be the run length for MTS items within a family run?
6. What are the acceptance/rejection criteria for MTO orders?
7. How much safety stock and cycle stock should be maintained for MTS items? (Soman et al 2002, 12).

However, adding MTO items or transferring MTS items to MTO can have a knock-on effect, such as an increase in the inventory of the MTS items in order to achieve similar levels of service. Given that many chilled food products have relatively short shelf lives, this could lead to significant levels of unnecessary waste.

Soman et al (2004) state how “No inventory for MTO items means an increase in the number of steps and hence the machine utilisation” (ibid.) which in turn increases production lead-time. However, inventory can only be reduced by increasing the cycle stock and safety stock of the MTS items. Hence there is a trade-off between decreasing inventory of some items and increasing cycle and safety stock of other items. In addition, the limited shelf-life of some products can pose limits on safety stock levels and cycle length.

Soman et al (2004) classify three of the most common MTO-MTS characteristics: plant characteristics, product characteristics and production process characteristics. These are expanded upon as follows:

1. Plant characteristics;
    a. Expensive capacity with flow shop orientated design due to conventional small product variety and high volumes;
    b. Extensive sequence-dependent set-up and cleaning times between different product types;
2. Product characteristics;
    a. Variation in supply and quality of raw material;
    b. Limited shelf life for raw materials, semi-finished and finished products;
    c. Volume or weight as the unit of measure unlike discrete manufacturing;
3. Production process characteristics;
    a. Processes having variable yield and processing time;

b. A divergent flow structure – a product can be packaged into many SKU sizes;
c. Multiple recipes for a product;
d. Packaging stage is labour intensive, whereas processing stage is not;
e. Production rate is mostly determined by the capacity;

In addition, Soman et al (2004) have made the following assumptions during the planning stage of a combined MTO-MTS production system:

1. No intermediate storage is possible and a MTO-MTS production system is considered as single equipment;
2. The equipment can be considered as the bottleneck facility out of the processing and packaging stages;
3. Demand is uncertain;
4. For MTO items, no finished goods inventory is maintained;
5. Each order for a MTO product has an agreed-upon due date;
6. The firm aims to deliver the product by this date;
7. MTS orders are fulfilled from the stock;
8. All products have a limited shelf life;
9. A sequence-dependent setup time is incurred whenever there is a changeover from production of one product to another, which makes product families appear attractive;
10. Changeover times between products of the same family are relatively less and can provide extra processing time, especially in the high utilisation situation;
11. Performance of the manufacturing system will be judged by capacity utilisation, order-focussed measures for the MTO product and product-focussed measures for the MTS items;

(Soman et al 2004, 229).

3.6. Conclusion

This chapter has discussed reasons why a philosophy of continuous improvement is necessary within the CFSC, with a special focus upon Lean (which minimises waste) and Sigma Six (which minimises variation). It has also discussed the differences between “push” and “pull” system strategies. It has outlined some of the issues involved in establishing a pull system, given that the concept of customer “pull” is important from a Lean perspective. In turn, this has led to a discussion of the problem of having to decide which products should be MTO and which should be MTS, as well as the issues involved with establishing a mixed or hybrid strategy.

Chapter Four – Managing Uncertainty within the CFSC

4.1. Introduction

The chilled food sector contains many unique problems concerned with uncertain data and/or uncertain variation in the products being produced. These include short self-life products, uncertainty of size and quality (i.e. eggs or fruit and vegetables), uncertain yield sizes, uncertain demand for products being sold and so forth. In addition, many recent food scandals (such as the 2013 horsemeat scandal) have put pressure upon suppliers and retailers to ensure that the overall level of perceived risk to food consumers is negligible.

Therefore, what is required is an effective strategy for managing these uncertainties within acceptable tolerance limits. One such technique is data envelopment analysis (DEA), in which the ratio of output data compared to the relevant input data is used to provide an overall measure of efficiency. However, in order to fully contextualise DEA within the context of uncertain environments, several theories related to the technique will need to be discussed. Hence, this chapter is structured in relation to the following research questions:

1. What is meant by indeterminacy and uncertainty?
2. What is meant by Dempster-Shafer theory and why is this technique inadequate for managing the uncertainties within the CFSC?
3. Why should uncertainty theory be considered a more favourable approach to managing uncertainties within the CFSC?
4. What is meant by the terms “bounded rationality” and the “satisficing organism” and how are these terms relevant to the problem of managing the uncertainties within the CFSC?

5. How are uncertainty and bounded rationality related to game theory?
6. What is meant by data envelopment analysis (DEA) and how is this related to the issues so far discussed?
7. How can DEA be used to ensure that the overall perceived risk to the customer remains minimal?

This chapter will follow the structure as given in the Figure 4.1 below:

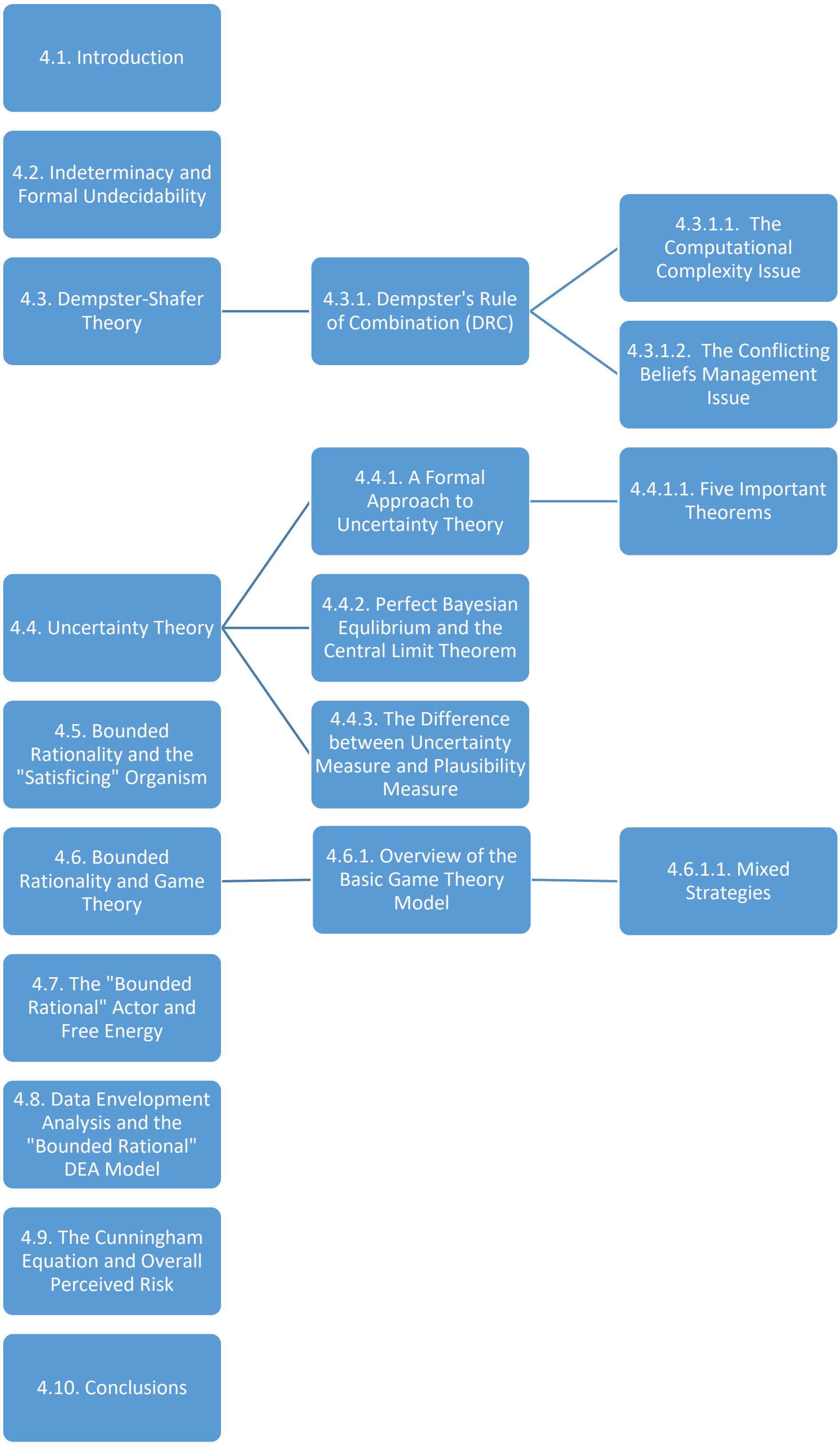

Figure 4.1. Diagram to illustrate the structure of Chapter Four

4.2. Indeterminacy and Formal Undecidability

Gödel (1931) proposes the following theorem of formal undecidability:

> Zu jeder ω-widerspruchsfreien rekursiven Klasse, x, von *Formeln* gibt es rekursive *Klassenzeichen*, r, so daß weder $v\ Gen\ r$ noch $\mathrm{Neg}(\mathrm{v\ Gen\ r})$ zu $\mathrm{Flg}(\mathrm{x})$ gehört (wobei v die *freie Variable* aus r ist).
>
> (Gödel 1931, 187).

This is translated as:

> For every ω-consistent primitive recursive class, x, of formulae there exists a recursive class, r, such that neither $v\ Gen\ r$ nor $\mathrm{Neg}(\mathrm{v\ Gen\ r})$ belongs to $Flg(x)$, where v is the free variable of r.

This theorem asserts that there exists a class of formal statements, which can neither be proven nor disproven.

For example, Bertrand Russell's conjecture that "there is a small china teapot in orbit between the Earth and Mars" (Russell 1952, 547) is a completely indeterminate statement since there is no plausible means of testing this statement's validity. However, the conjecture that "it is going to rain today" is a determinate statement, given that we can more-readily test this hypothesis (i.e. by looking out of the window).

However, if we consider Gödel's second incompleteness theorem (i.e. Theorem XI of Gödel's 1931 paper):

> Sei x eine beliebige rekursive widerspruchsfreie Klasse von *Formeln*, dann gilt: Die Satzformel, welche besagt, daß x widerspruchsfrei ist, ist nicht x-beweisbar; insbesondere ist die Widerspruchsfreiheit von P in P unbeweisbar, vorausgesetzt, daß P widerspruchsfrei ist (im entgegengesetzten Fall ist nattirlieh jede Aussage beweisbar).
> (Godel 1931, 196)

This is translated as

> If x is any recursive, non-contradictory class of formulas, then the theorem which states that x is non-contradictory is not x-provable; In particular, the contradiction-freeness of P in P is unprovable, provided that P is non-contradictory (in the opposite case every proposition is provable).

This theorem asserts that we can continue adding to and refining the existing model (i.e. a "recursive, non-contradictory class of formulas") as long these modifications are consistent with the existing model. Hence, given that our study is concerned with the reduction of wastage/variation/risk/etc. (i.e. “non-contradictory”) we can never completely eliminate these factors. We can however continue to develop and refine the existing model.

4.3. Dempster-Shafer Theory

Dempster-Shafer theory (Chen et al 2014) is based on a frame of discernment Θ which is the set of finite mutually exclusive propositions and hypotheses about a given problem domain. In addition, the power set 2^{Θ} is the set of all possible subsets of Θ including the empty set, $\emptyset$. Hence, if

$$\Theta = \{a, b\} \qquad \text{(Equation 4.1)}$$

then

$$2^{\Theta} = \{\emptyset, \{a\}, \{b\}, \Theta\} \qquad \text{(Equation 4.2)}$$

In addition, a mass value m between 0 and 1 is assigned to each subset of the power set (i.e. that a proposition is either “true” or “false”). Hence,

$$m : \ 2^{\Theta} \rightarrow [0,1] \qquad \text{(Equation 4.3)}$$

In addition, the mass of the empty set is always defined as being equal to zero. Hence,

$$m(\emptyset) = 0 \qquad \text{(Equation 4.4)}$$

However, the sum of the masses of the remaining members of the power set must be equal to 1. Hence,

$$\sum_{A \subseteq \Theta} m(A) = 1 \qquad \text{(Equation 4.5)}$$

Hence, the quantity $m(A)$ is the measure of probability of event A happening. In addition, we define the belief degree bel that event A is going to happen as $bel(A)$, and the plausibility pl or possibility measure that event A is going to happen as $pl(A)$. Hence,

$$bel(A) = \sum_{B \subseteq A} m(B) \qquad \text{(Equation 4.6)}$$

$$pl(A) = \sum_{B \cap A \neq \emptyset} m(B) \qquad \text{(Equation 4.7)}$$

Hence, these two statements are related via the following statement

$$pl(A) = 1 - bel(\neg A) \qquad \text{(Equation 4.8)}$$

Hence, we can also express this statement as

$$pl(A) = 1 - bel(A^c) \qquad \text{(Equation 4.9)}$$

Where A^c is the complement of event A. Hence, the relationship between belief degree, plausibility and uncertainty can be illustrated by Figure 4.2.

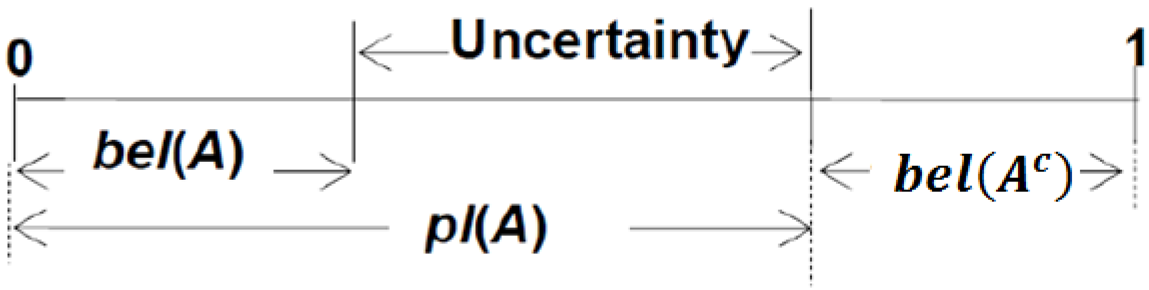

Figure 4.2. Diagram to illustrate the relationship between belief degree, plausibility and uncertainty based on Chen et al (2014) and Lawrence (2004).

Hence, uncertainty emerges because it is plausible for a condition to be true and not true simultaneously. Hence, Dempster-Shafer theory asserts that the following condition is always true:

$$m(A) \leq bel(A) \leq pl(A) \qquad \text{(Equation 4.10)}$$

However, this condition also infers that

$$m(A) \leq pl(A) \qquad \text{(Equation 4.11)}$$

i.e the plausibility (or possibility) of a condition being true outweighs the evidential weighting of that condition being true, which is potentially catastrophic.

4.3.1. Dempster's Rule of Combination (DRC)

Dempster's Rule of Combination (DRC) is concerned with uniting two independent sets of mass functions on Θ. However, there are two main disadvantages of DRC (Chen 2014, 5):

1. The computational complexity issue;
2. The conflicting belief management issue.

Each of these will need to be discussed in order to illustrate the potential weaknesses of DRC when faced with multiple variables under uncertain conditions.

4.3.1.1. The Computational Complexity Issue

If we consider the general form for independent sets of mass functions on Θ we obtain the expression

$$m_{1,2,\ldots n}(A) = (m_1 \oplus m_2 \ldots \oplus m_n)(A) \qquad \text{(Equation 4.12)}$$

Hence, the expression for K becomes very complicated very quickly. We would either have to evaluate this expression in multiple stages (which is computationally complicated), or else the partition given by $(m_1 \oplus m_2 \ldots \oplus m_n)(A)$ would be very difficult to read as $m_n \to \infty$. Accordingly, if there are n elements on Θ there will be 2^{n-1}focal elements for the mass function, which would require a computation of 2^n intersections. Clearly, when dealing with large sets of uncertain data, DRC proves to be an inadequate technique.

4.3.1.2. The Conflicting Beliefs Management Issue

The conflicting beliefs management problem was first identified by Zadeh (1986). However, Chen et al (2014) provide the following example of a conflicting beliefs problem:

Consider three suspects in a crime, Jon, Mary and Mike, and two witnesses, W1 and W2 (Chen et al 2014, 5). The first witness, W1, assigns a mass value of $m_1 = 0.9$ to the statement “Mike is guilty”, whilst the second witness, W2, assigns a mass value of $m_2 = 0.1$ to the statement “Mary is guilty”. Accordingly, the DRC algorithm returns a value of $K = 0.99$ which infers a value of 1 for the statement “Mary is guilty”. Yet given that the statement “Mary is guilty” has been assigned a mass of $m_2 = 0.1$ this conclusion has contradicted the balance of evidence as given by witness W2.

Dezert et al (2012) present the conjecture of 100 doctors attempting to diagnose a disease. Of these, 99 doctors diagnose disease C as being the most likely, but they cannot completely rule out diseases A and B. By comparison, 1 doctor has rejected disease C but favours disease A as being the most likely cause. Yet because there is a possibility that the 1 doctor is correct and the other 99 doctors are wrong, DRC will still honour the opinion of the 1 doctor over the other 99 doctors in the lack of additional evidence. However, whilst we might consider that the 1 doctor is a specialist, we must also recall that doctors are trained to employ standard diagnostic techniques. Hence, whilst DRC can be useful in identifying concepts which we might not have previously considered, these kinds of results will also conflict with common sense arguments.

Liu (2016) proposes the conjecture of a bridge's strength as being "exactly 100 tons" or "not exactly 100 tons" (Liu 2016, 480). Hence, common sense would indicate that the outcome should be "not exactly 100 tons" given that the bridge strength is plausibly "greater than 100 tons", "exactly one hundred tons" or "less than 100 tons" (i.e. there is a two out of three probability that "not exactly 100 tons" is true). However, DRC would return a value of both events being equally likely, which is a contradiction.

Hence, because the "plausibility of being true" outweighs the "evidential weighting of being true" we need to consider an alternative strategy.

4.4. Uncertainty Theory

Uncertainty theory may be considered as a development of the uncertain model proposed by Dempster-Shafer theory, but in a form which takes into account the computational complexity problem and the conflicting belief management problem.

According to Liu (2016):

Real decisions are usually made in the state of indeterminacy. For modelling indeterminacy, there exist two mathematical systems, one is probability theory (Kolmogorov, 1933) and the other is uncertainty theory (Liu, 2007). Probability is interpreted as frequency, while uncertainty is interpreted as personal belief degree (Liu 2016, 1).

Hence, whilst probability theory and uncertainty theory are closely related and share many of the same models, probability is modelled upon cumulative frequency whilst uncertainty theory is modelled upon belief degree. Hence, the difference between the two which gives rise to uncertainty is the presence of incomplete data. We must then consider indeterminacy as "the phenomena whose outcomes cannot be exactly predicted in advance" (Liu 2016, 1) because the data set is incomplete.

Hence, we must consider a range of ambiguity between the degrees of "determinate" and "completely indeterminate". This is known as the indeterminacy distribution function. This is illustrated in the Figure 4.3 below:

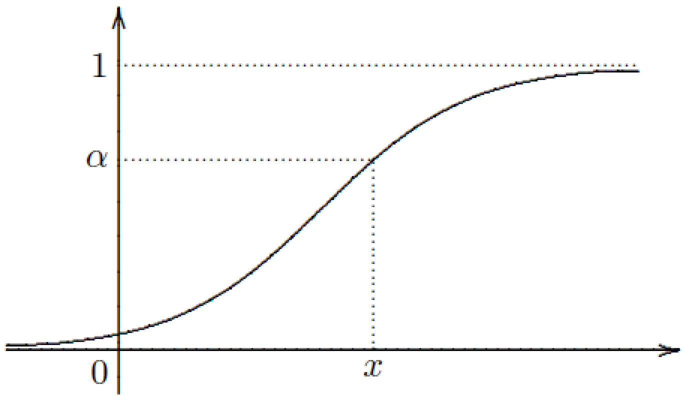

Figure 4.3. based on (Liu 2016, 2) to illustrate the distribution function of some indeterminate quantity.

Hence, the distribution pattern between an outcome being completely determinate or completely indeterminate lies on a sliding scale between 0 and 1 as follows:

1. If the distribution is 0 then it is 0% possible that the outcome falls to the left of the current point and 100% certain that the outcome falls to the right of the current point.
2. If the distribution is 1 then it is 100% certain that the outcome falls to the left of the current point and 0% possible that the outcome falls to the right of the current point.
3. If the distribution is 0.6 then it is 60% certain that the quantity falls to the left of the current point and 40% certain that the quantity falls to the right of the current point.
4. If a distribution is 0.5 then it is equally likely that an event and its complementary event will occur.
5. In general, if a distribution is α $(0 \leq \alpha \leq 1)$ then it is $\alpha \times 100\%$ certain that the quantity falls to the left of the current point and $(1 - \alpha) \times 100\%$ certain that the quantity falls to the right of the current point.

Accordingly, the distribution function of an indeterminate event provides a measure of the belief degree that the event will happen (or that a statement is true).

4.4.1. A Formal Approach to Uncertainty Theory

Uncertainty theory itself is formalised through the following three axioms:

Axiom 1. (Normality axiom) $M\{\Gamma\} = 1$ for the universal set $\quad$ (Equation 4.13)

Axiom 2. (Duality axiom) $M\{\Lambda\} + M\{\Lambda^c\} = 1$ for any event $\quad$ (Equation 4.14)

Axiom 3. (Subadditivity axiom) For every countable sequence $\Lambda_1, \Lambda_2, \ldots$

$$M\left\{\bigcup_{i=1}^{\infty} \Lambda_i\right\} \leq \sum_{i=1}^{\infty} M\{\Lambda_i\} \qquad \text{(Equation 4.15)}$$

Accordingly, the set function M is called the uncertainty measure if it satisfies the normality, duality and subadditivity axioms. The uncertainty measure is the belief degree that an uncertain event will happen. Accordingly, belief degree changes as the state of knowledge improves (Liu 2016, 13). We also note that the symbol "M" is used as the uncertainty measure in order to distinguish it from the mass $m(A)$ of Dempster-Shafer theory. Hence, we can re-express Figure 4.3 as an uncertainty space with $M\{\Lambda\}$ taking a value between "0" and "1":

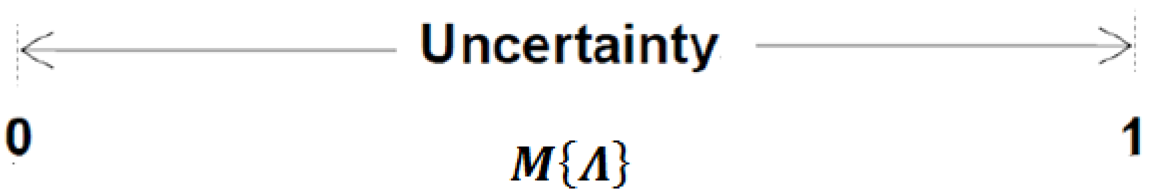

Figure 4.4. to illustrate how uncertainty measure $M\{\Lambda\}$ takes a value between 0 and 1.

Hence, the Dempster-Shafer condition (equation 4.10)

$$m(A) \leq bel(A) \leq pl(A)$$

is replaced by

$$M\{0\} \leq M\{\Lambda\} \leq M\{1\} \quad \text{(Equation 4.16)}$$

Hence, if we define x as an uncertainty space "Λ" taking values between "0" and "1", and $M\{\Lambda\}$ is the uncertainty measure, Gödel's first undecidability theorem predicts that $M\{\Lambda\}$ cannot be resolved except at the extreme values "0" and "1".

4.4.1.1. Five Important Theorems

In addition, Liu adds the following theorems:

Theorem 1. (Monotonicity) The uncertain measure is a monotone increasing set function, i.e. for any events $\Lambda_1$and Λ_2 with $\Lambda_1 \subset \Lambda_2$

$$M\{\Lambda_1\} \leq M\{\Lambda_2\} \quad \text{(Equation 4.17)}$$

Proof: from the normality axiom, $M\{\Gamma\} = 1$ and from the duality axiom $M\{\Lambda\} + M\{\Lambda^c\} = 1$. Therefore, $M\{{\Lambda_1}^c\} = 1 - M\{\Lambda_1\}$. Since $\Lambda_1 \subset \Lambda_2$ it follows that $\Gamma = {\Lambda_1}^c \cup \Lambda_2$. Hence, from the subadditivity axiom:

$$1 = M\{\Gamma\} \leq M\{{\Lambda_1}^c\} + M\{\Lambda_2\} = 1 - M\{\Lambda_1\} + M\{\Lambda_2\} \quad \text{(Equation 4.18)}$$

Hence,

$$M\{\Lambda_1\} \leq M\{\Lambda_2\} \quad \text{(Equation 4.19)}$$

Theorem 2. The empty set ∅ always has an uncertain measure zero. i.e.

$$M\{\emptyset\} = 0 \quad \text{(Equation 4.20)}$$

Proof: since $\emptyset = \Gamma^c$ and $M\{\Gamma\} = 1$, it follows from the duality axiom that

$$M\{\emptyset\} = 1 - M\{\Gamma\} = 1 - 1 = 0 \qquad \text{(Equation 4.21)}$$

Theorem 3. The uncertain measure always takes values between 0 and 1. i.e.

$$0 \leq M\{\Lambda\} \leq 1$$

Proof: from the monotonicity theorem it follows that $0 \leq M\{\Lambda\} \leq 1$ because $\emptyset \subset \Lambda \subset \Gamma$

and $M\{\emptyset\} = 0$ and $M\{\Gamma\} = 1$.

Theorem 4. Let $\Lambda = \Lambda_1, \Lambda_2, \ldots$ be a sequence of events with $M\{\Lambda_i\} \to 0$ as $i \to \infty$. For any event Λ

$$\lim_{i\to\infty} M\{\Lambda \cup \Lambda_i\} = \lim_{i\to\infty} M\{\Lambda - \Lambda_i\} = M\{\Lambda\} \qquad \text{(Equation 4.22)}$$

That is, an uncertain event remains unchanged if the event is enlarged or reduced by an

event with an uncertainty measure of zero.

Proof: from the monotonicity theorem and the subadditivity axiom, it follows that:

$M\{\Lambda\} \leq M\{\Lambda \cup \Lambda_i\} \leq M\{\Lambda\} + M\{\Lambda_i\}$ for each i. Hence, $M\{\Lambda \cup \Lambda_i\} \to M\{\Lambda\}$ by using

$M\{\Lambda_i\} \to 0$. Since $(\Lambda - \Lambda_i) \subset \Lambda \subset \big((\Lambda - \Lambda_i) \cup \Lambda_i\big)$, we have

$$M\{\Lambda - \Lambda_i\} \leq M\{\Lambda\} \leq M\{\Lambda - \Lambda_i\} + M\{\Lambda_i\}$$

Hence,

$M\{\Lambda - \Lambda_i\} \to M\{\Lambda\}$ as $M\{\Lambda_i\} \to 0$ (Equation 4.23).

Theorem 5. For events $\Lambda_1, \Lambda_2, \ldots$

$$\lim_{i\to\infty} M\{\Lambda_i\} > 0, if \;\; \Lambda_i \uparrow \Gamma \qquad \text{(Equation 4.24}a\text{)}$$

$$\lim_{i\to\infty} M\{\Lambda_i\} < 1, if \;\; \Lambda_i \downarrow \emptyset \qquad \text{(Equation 4.24}b\text{)}$$

Proof: if we assume that $\Lambda_i \uparrow \Gamma$, since $\Gamma = \cup_i \Lambda_i$ it follows from the subadditivity axiom that

$$1 = M\{\Gamma\} \leq \sum_{i=1}^{\infty} M\{\Lambda_i\}$$

Since $M\{\Lambda_i\}$ is increasing with respect to i we have $\lim_{i\to\infty} M\{\Lambda_i\} > 0$. If $\Lambda_i \downarrow \emptyset$ then ${\Lambda_i}^c \uparrow \Gamma$. It follows from the first inequality and the duality axiom that

$$\lim_{i\to\infty} M\{\Lambda_i\} = 1 - \lim_{i\to\infty} M\{{\Lambda_i}^c\} < 1$$

Hence,

$$\lim_{i\to\infty} M\{\Lambda_i\} > 0, if \;\; \Lambda_i \uparrow \Gamma$$

$$\lim_{i\to\infty} M\{\Lambda_i\} < 1, if \;\; \Lambda_i \downarrow \emptyset$$

However, Liu also argues that “All belief degrees are wrong, but some are useful” (Liu 2016, 5). By this he means that a belief degree will improve the more it approximates to the frequency of the indeterminate quantity. We can prove this by considering a perfect Bayesian equilibrium and the central limit theory.

4.4.2. Perfect Bayesian Equilibrium and the Central Limit Theorem

A perfect Bayesian equilibrium (PBE) is an assignment of data distributions, such that the sum of these distributions in any given information set is equal to one (Shamir 2011, 355). Hence, a PBE is essentially based on a Markov decision chain model. The following brief overview of a Markov decision chain is based on Quinn (2000, 8, 9) and Osaki and Mine (1968).

A Markov chain has k states $1, 2, 3, \dots, k$. The probability that the system is in state i at any observation after it was in state j at the preceding observation is given by:

$$P\{X_n = j | X_{n-1} = i\} = P_{ij} \quad \text{(Equation 4.25)}$$

where the distribution X_n is in state j at time t_1 given that the distribution X_{n-1} is in state i at time t_0 (Osaki and Mine 1968, 359).

We also note that

$$\sum_{j=1}^{\infty} P_{ij} = 1, \ \text{ for } i = 1,2, \dots \ \text{ and } P_{ij} \geq 0 \quad \text{(Equation 4.26)}$$

However, it is necessary that

$$p(x_2, t_2 | x_1, t_1) = \int p(x_2, t_2 | x_3, t_3)\, p(x_3, t_3 | x_2, t_3) dx_3 \quad \text{(Equation 4.27)}$$

for the initial distribution of P_{ij} to describe the statistics of the process. This is a paraphrasing of Smoluchowski's equation or the Kolmogorov condition (Risken 1984, 2). Hence we can invoke the central limit theorem (García-Palacios 2004, 21), which states that as the number of processes in the system tends to infinity, the initial distribution of P_{ij} will adopt a jointly Gaussian distribution (JGD). Hence, if we assume that the initial distribution adopts a JGD we can prove that the accuracy of belief degrees will improve the more information becomes available.

Hence, given a large enough sample, the belief degree of an event occurring will approximate to the probability of that event occurring. However, with a lack of samples, there is also a lack of cumulative frequency, which means that all belief degrees are only valid for a limited range of data. Hence, with limited data the accuracy of the prediction is likely to be inaccurate.

4.4.3. The Difference between Uncertainty Measure and Plausibility Measure

If we return to the DRC equation as given by Chen et al (2014)

$$m_{1,2}(A) = (m_1 \oplus m_2)(A)$$

We are given DRC is concerned with uniting two independent sets of mass functions on Θ. However, if we express DRC in terms of uncertainty measures and plausibility measures, Liu (2016) states that

$$M\{\Lambda_1 \cup \Lambda_2\} = M\{\Lambda_1\} \vee M\{\Lambda_2\} \qquad \text{(Equation 4.28)}$$

only holds when events Λ_1 and Λ_2 are independent of each other. However, in Dempster-Shafer theory the plausibility statement

$$pl\{\Lambda_1 \cup \Lambda_2\} = pl\{\Lambda_1\} \vee pl\{\Lambda_2\} \qquad \text{(Equation 4.29)}$$

holds whether or not events Λ_1 and Λ_2 are independent of each other (Liu 2016, 480). Hence, this assertion can be read as an alternative expression of the conflicting beliefs management issue – that is, the plausibility of something being "true" has taken a higher precedent over the belief degree or probability of it being "true". This is significant, given that scientific experiment is chiefly concerned with testing the difference between dependent and independent variables.

Hence, uncertainty theory can be considered as a development of/from Dempster-Shafer theory, but does so in a form which is much clearer to understand and which does not contradict common sense arguments and evidential weightings.

4.5. "Bounded Rationality" and the "Satisficing" Organism

"Bounded rationality" refers to the idea that people are limited in the decisions that they make because the information they are given is incomplete. The origin of the term can be traced through a history of similar terms, beginning with "limited intelligence" in 1840, when the German philosopher Immanuel Kant sought to determine the nature and limits of human knowledge (Klaes 2003, 9). Hence, bounded rationality is related to many similar terms, including indeterminacy and uncertainty, which infer limited or restricted access to information pertaining to real-world data.

However, the concept of a "bounded rational" system in terms of adaptation and continuous improvement develops from Simon (1957) and the "satisficing" organism:

> Since the organism, like those of the real world, has neither the senses nor the wits to discover an "optimal" path – even assuming the concept of optimal to be clearly defined – we are concerned only with finding a choice mechanism that will lead it to pursue a "satisficing" path that will permit satisfaction at some specified level of all of its needs (Simon 1957, 270, 271).

Hence, any "real" world entity can only make choices based upon the best available data. If the data set is known to be incomplete the solution is said to "satisfice" (i.e. as a contraction of "satisfy" and "suffice") the problem, even though an optimal solution may be possible given more data. This infers that a satisficing organism is also one which seeks to continuously improve itself by gathering more information about its (working) environment. Hence, “bounded rationality” is very closely related to indeterminacy.

Jones (1999) expands upon the fundamental characteristics of Simon’s “satisficing” organism:

1. The bounded cognitive ability of the organism, combined with the complexity of the environment in which it operates, limits its capacity to plan long behaviour sequences;
2. The organism will set aspiration levels for each goal it faces;
3. The organism tends to tackle goals sequentially rather than simultaneously “because of the bottleneck of short-term memory”;
4. The organism will “satisfice” rather than optimise search criteria, since it is working with limited data (Jones 1999, 301).

Hence, once the basic needs of the organism have been identified, the threshold limits which “satisfice” these needs can be outlined within the data available.

4.6. Bounded Rationality and Game Theory

There are two kinds of games:

1. Games with perfect information (also called a complete information game), such as chess, where players are informed about the previous moves in the game;
2. Games with imperfect information (also called a game with incomplete information), where players do not have common knowledge of the game being played.

Therefore, a "bounded rational" actor is an actor that is competing in a game with imperfect information. Accordingly, players may only have a limited knowledge of:

1. The "rules" of the game or else its basic and extended form;
2. The number of players involved within the game
3. The payoff function – either their own or that of the other players;
4. The set of possible strategies available to each player at any instance within the game;
5. The probability distribution of moves "played" within the game (Harsanyi 1968).

However, Harsanyi (1968) demonstrated that the model for a game of imperfect information effectively reduces to a game G^* which is equivalent to one or more perfect information games, G. Hence if we consider G^* is the "best possible" game which can be played based upon the information available, we can state that

$$G^* \subseteq G \qquad \text{(Equation 4.30)}$$

and

$$G = \{G_1, \dots, G_n\} \qquad \text{(Equation 4.31)}$$

is the set of best possible games which can be played. Hence, the general model for a "bounded rational" actor will be better contextualised through an overview of the basic game theory model.

4.6.1. Overview of the Basic Game Theory Model

The following discussion is based on Dresher (1961), Harsanyi (1968) and Jones (1980). We first consider a game of perfect information.

If A is the set of strategies of Player 1 (i.e. "White") and B is the set of strategies of Player 2 (i.e. "Black") there are three possible outcomes:

1. Player 1 plays a pure strategy which will win regardless of the strategy that player 2 plays.
2. Both players are using pure strategies, such that the game will end in a draw regardless of what strategy each player chooses.
3. Player 2 plays a pure strategy which will win regardless of the strategy that Player 1 plays.

Hence, these three outcomes can be classified as saddle points, such that we have a "win" (i.e. $+1$), "draw" (i.e. 0), or "lose" (i.e. -1), which result in termination of the game.

However, in games like chess the number of possible moves available becomes so large (i.e. Shannon's number gives $> 10^{120}$ possible moves) that it would be impossible to calculate the most optimal strategy to ensure a win for these types of games. Instead, at any particular stage in the game, Player 1 will play a move $a_i \in A$ and Player 2 will play a move $a_j \in A$ in response. This implies that at any time in the game, each move made by either Player 1 or Player 2 will only be optimal based upon the current state of the game. We might also consider that at any stage in the game after the opening move, $a_1 \in A$, either Player 1 or Player 2 may change strategies in line with the strategy currently being played by the opponent. This change of strategy by either player may constitute an improvement or deterioration in their performance.

However, in terms of relationships between suppliers, retailers and customers within the supply chain, it is assumed that the working relationships between parties involved will continue for an indefinite period. We then need to consider whether it is possible or indeed realistic for both retailers and suppliers to play a pure strategy within a game of imperfect information. The choice of strategy is then made in terms of finding the optimum pay-off for a given state-of-play within the game. Hence we need to reconsider the problem in terms of mixed strategies.

4.6.1.1. Mixed Strategies

From first principles, we consider that player 1 has m strategies available, such that

$$i = 1,2, \dots, m$$

We then consider that player 2 has n strategies available, such that

$$j = 1,2, \dots, n$$

Hence, player 1 has a payoff matrix A given by

$$A = \left(a_{ij}\right)_{m\times n} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1m} \\ a_{21} & a_{22} & \dots & a_{2m} \\ \vdots & \vdots & \dots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \qquad \text{(Equation 4.32)}$$

Hence, player 1 wants a_{ij} to be as large as possible, whereas player 2 wants a_{ij} to be as small as possible.

If we then consider x_i as the probability that player 1 will select strategy i then the mixed strategy or distribution X of x_i is given by

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_m \end{bmatrix}, \qquad x_i \geq 0 \qquad \text{(Equation 4.33)}$$

and

$$\sum_{i=1}^{m} x_i = 1 \qquad \text{(Equation 4.34)}$$

Similarly, if we consider y_j as the probability that player 1 will select strategy j then the mixed strategy or distribution Y of y_j is given by

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_m \end{bmatrix}, \qquad y_j \geq 0 \qquad \text{(Equation 4.35)}$$

and

$$\sum_{j=1}^{n} y_j = 1 \qquad \text{(Equation 4.36)}$$

Hence, the payoff h_i to player 1 for choosing strategy i when player 2 uses the mixed strategy Y is given by

$$h_i = \sum_{j=1}^{n} a_{ij} y_j \qquad \text{(Equation 4.37)}$$

However, the payoff k_j to player 2 for choosing strategy j when player 1 uses the mixed strategy X is given by

$$k_j = \sum_{i=1}^{m} a_{ij} x_i \qquad \text{(Equation 4.38)}$$

Hence, if we change these models to signify the optimum strategies which player 1 and player 1 must play in order to reach equilibrium, we have

$$\max_i \sum_{j=1}^{n} a_{ij} y_j^* = \min_j \sum_{i=1}^{m} a_{ij} x_i^* = v \qquad \text{(Equation 4.39)}$$

Hence,

$$\max_i u_i^* = \min_j l_j^* = v \qquad \text{(Equation 4.40)}$$

Hence, we have the limit

$$u_i^* \leq v \leq l_j^* \; for \; all \; i, j \qquad \text{(Equation 4.41)}$$

Hence, since $u_i^* \leq v$ we can then consider the set of strategies $S_1$for which $u_i^* < v$ and the set of strategies S_2 for which $u_i^* = v$.

Hence,

$$v = \sum_{i=1}^{m} u_i^* x_i^* = v \sum_{S_2} x_i^* + \sum_{S_1} u_i^* x_i^* \qquad \text{(Equation 4.42)}$$

Hence,

$$v\left(1 - \sum_{S_2} x_i^*\right) = \sum_{S_1} u_i^* x_i^* \qquad \text{(Equation 4.43)}$$

Hence,

$$v \sum_{S_1} x_i^* = \sum_{S_1} u_i^* x_i^* \qquad \text{(Equation 4.44)}$$

Hence,

$$\sum_{S_1} (v - u_i^*) x_i^* = 0 \qquad \text{(Equation 4.45)}$$

Hence, in the case where $u_i^* = v$ we have

$$v - u_i^* = 0 \qquad \text{(Equation 4.46)}$$

and

$$x_i^* \neq 0 \qquad \text{(Equation 4.47)}$$

and when $u_i^* < v$ we have

$$v - u_i^* \neq 0 \qquad \text{(Equation 4.48)}$$

and

$$x_i^* = 0 \qquad \text{(Equation 4.49)}$$

Hence, we have also demonstrated that a "bounded rational" actor is effectively equivalent to a limitation being imposed upon the mixed strategy which is available to that actor.

4.7. The "Bounded Rational" Actor and Free Energy

Ortega and Braun (2013) propose a thermodynamically inspired formalisation of bounded rational decision-making where information processing is modelled as state changes in thermodynamic systems that can be quantified by differences in free energy. Accordingly, a model is proposed by which the lowest-possible free energy state equilibrium corresponds to the most optimum level of utility available for any given function. This is the beginning of their argument for three different kinds of actor:

1. A perfectly rational actor who has achieved the maximum possible utility
2. A bounded rational actor who only has access to a fraction of the available utility
3. A "perfectly irrational" actor who has no utility.

It follows that this analogy is equivalent to Simon's "satisficing organism" in that decisions are often made based on a fraction of the total data available, or when the data set is incomplete for some reason.

In addition, when we consider the range from uncertainty theory

$$M\{0\} \leq M\{\Lambda\} \leq M\{1\}$$

It follows that we can express the three kinds of actor in terms of measures of uncertainty. Hence, we have:

1. A perfectly rational actor is one whose measure of uncertainty is $M\{1\}$, i.e. the actor has an absolute certainty of the information being true.
2. A bounded rational actor is one whose measure of uncertainty is $M\{\Lambda\}$, i.e. the actor has only some fraction, Λ, of the information being true.
3. A "perfectly irrational" actor is one whose measure of uncertainty is $M\{0\}$, i.e. it is absolutely certain that the information is not true. Therefore, it would be completely irrational to act upon information which has been demonstrated to be not true.

Hence, we can extend Ortega and Braun (2013)'s reasoning to propose the general model for a "bounded rational" actor:

$$\lim_{\beta \to 0} \frac{1}{\beta} \log Z = \sum_{x} p(x)\, U(x) \qquad \text{(Equation 4.50)}$$

$$0 \leq p(x) \leq 1$$

$$0 \leq U(x) \leq 1$$

Accordingly, the condition

$$0 \leq p(x) \leq 1$$

can be taken as being equivalent to the uncertainty theory condition

$$M\{0\} \leq M\{\Lambda\} \leq M\{1\}$$

given that uncertainty measure improves towards probability measure in accordance with the central limit theory.

The Ortega and Braun (2013) model itself is based upon finding the lowest possible free energy state as a means of measuring effective utility within a bounded rational system. Here β can be taken as an approximation of average computation time.

It also follows that as $\beta \to 0$, $p(x) \to 1$, and the uncertainty measure $\to M\{1\}$, which is the model for a perfectly rational actor. Hence computation time would be theoretically zero because $p(x)$ would be an absolute certainty that event x was going to occur.

Hence, this line of reasoning leads us directly into a discussion of data envelopment analysis (DEA) models.

4.8. Data Envelopment Analysis and the "Bounded Rational" DEA Model

Data envelopment analysis was first initiated by Charnes et al (1978). Cooper et al (2007) explain that DEA has subsequently been applied to a variety of applications because it allows the decision maker to assess decision making units (DMUs) as being either efficient or inefficient (Cooper et al 2007, xxix) by comparing output data with its associated input data.

Cook and Seiford (2009) present a review of DEA techniques which have emerged since Charnes (1978). However, the main limitation of the paper is that it is concerned with methods rather than applications, with a special focus upon:

1. Various models for measuring efficiency of DMUs;
2. Various approaches to incorporating restrictions on multipliers;
3. Considerations regarding the status of variables;
4. Modelling data variation.

Nevertheless, Cook and Seiford (2009) and Cooper et al (2007) provide many useful approaches for using DEA under uncertain conditions and when the information available is limited.

According to Charnes et al (1990) the feasible region for the input multiplier vector $\upsilon = (\upsilon_1, \upsilon_2, \dots, \upsilon_m)$ is defined as a polyhedral convex cone spanned by a set of k admissible non-negative direction vectors, a_l, $l = 1,2, \dots, k$. Hence a feasible υ can be expressed as

$$\upsilon = \sum_{l} \alpha_l \, a_l, \quad \alpha_l \geq 0, \;\; \forall l \qquad \text{(Equation 4.51)}$$

Hence, if we then take

$$v \equiv \lim_{\beta \to 0} \frac{1}{\beta} \log Z, \qquad \text{(Equation 4.52)}$$

$$\alpha_l \equiv p(x) \text{ and} \qquad \text{(Equation 4.53)}$$

$$a_l \equiv U(x), \qquad \text{(Equation 4.54)}$$

and if we recall the uncertainty condition

$$M\{0\} \leq M\{\Lambda\} \leq M\{1\}$$

we then have the "bounded rational" DEA model, since

$$v \equiv \sum_l p(x)\, U(x) \qquad \text{(Equation 4.55)}$$

The issue of DMU performance under uncertain input or output conditions is well discussed by Shabani et al (2012) who develop the free disposal hull (FDH) method of DEA analysis first proposed by Deprins et al (1984).

Wen et al (2014) propose a DEA model for uncertain inputs and outputs, where the objective is to "maximise the total slacks in inputs and outputs subject to constraints" (Wen et al 2014, 4). However, given that the slacks are based on a range of upper and lower estimates for input and output constraints, we can replace their reasoning with that of belief degree or uncertainty measure. Hence, with the application of our "bounded rational" DEA model, the problem is then reduced to deciding whether a DMU is efficient or inefficient based on the best available uncertainty measure.

Azizi and Ajirlu (2011) propose a DEA model which measures the efficiency of each DMU relative to the input frontier, which gives the worst relative efficiency. This measure is also known as the pessimistic efficiency or worst relative efficiency (Azizi and Ajirlu 2011, 4156).

Shabani et al (2012) and Goncharuk (2012) both propose DEA models for benchmarking purposes. Shabani et al (2012) propose a method for benchmarking sales agents under non-discretionary (or uncertain) factors and imprecise data. However, Goncharuk (2012) propose a DEA model for “the follower”, i.e. whether it is feasible for small and medium enterprises (SMEs) to choose a competitive strategy based on copying products, processes and technologies rather than to innovate their own unique strategy during times of financial crisis (Goncharuk 2012, 218). The problem is then one of identifying the “appropriate best practice” (Goncharuk 2012, 219) based on the most appropriate efficiency or inefficiency measurement.

Kumar and Basu (2008) use DEA to measure the Malmquist productivity index and its different components, including technological change, technical efficiency change and the change in scale efficiency in the Indian food industry. Given how technological innovation is one of the main issues identified across the agri-food chain, it follows that the approach could be adapted as a means of measuring the effectiveness of solutions to the issues identified within the cold chain, which include: technological challenges, product shelf life, waste, demand forecasting, customer satisfaction and price fluctuation.

Afzal and Ayaz (2013) use DEA to assess the efficiency of the Pakistan’s food sector for the period 2007 – 2010. However, very few studies have been done relating to the efficiency of the food sector using DEA when compared to studies concerned with the efficiency of the banking sector (Afzal and Ayaz 2013, 1314).

Han et al (2015) use an integrated interpretive structural model (interpretive ISM) DEA to assess the efficiency of the petrochemical industry. The difference with this technique is that it is based on partial correlation coefficients. It has the advantage that it eliminates irrelevant variables and removes subjective factors (Han et al 2015, 82).

Jahanshahloo et al (2007) propose techniques for reducing the computational complexity of linear programming (LP) models for DEA. Accordingly, the technique demonstrates that some DMUs can be classified without having to solve any LP models and only by some ratios.

Mostafaee and Saljooghi (2010) consider uncertain cost models based on uncertain data. This is based on two programs; an inner and an outer program. The inner program calculates the cost efficiency measure for each input-output set, whilst the outer program determines the input-output set that produces the highest cost efficiency measure for DMU_0 (Mostafaee and Saljooghi 2010, 596). This idea is extended for upper and lower bounds where the input and output data is presented in the form of ranges due to pricing information being incomplete (Mostafaee and Saljooghi 2010, 598).

4.9. The Cunningham Equation and Overall Perceived Risk

Mitchell (1998) observes that overall perceived risk is not only present in food scares but that it also helps to explain consumer spending habits (Mitchell 1998, 171). This reasoning also implies that overall perceived risk informs retail and demand forecasting strategies. In order to demonstrate this Mitchell (1998) cites the Cunningham equation (Cunningham 1967), since it presents the relationship between levels of uncertainty and the consequences which follow from the decision being made:

$$Overall\_perceived\_risk = \sum_{i}^{n} uncertainty_i \times adverse\_consequences_i$$

(Equation 4.56)

Where n is the number of types of loss i (Mitchell 1998, 171).

Hence, if we compare the Cunningham equation with the model for a "bounded rational" actor (from equation 4.55):

$$v \equiv \sum_{l} p(x)\, U(x)$$

This implies that $Overall\_perceived\_risk$ is directly proportional to $p(x)$, which is the level of uncertainty or indeterminacy present within the system. Hence, it also follows that $Overall\_perceived\_risk$ must adopt a range of values $M\{0\} \leq M\{\Lambda\} \leq M\{1\}$ as given by uncertainty theory.

Mitchell (1998) categorises risk under the following categories: performance risk, physical risk, financial risk, psychosocial risk and time risk. These are given in Table 4.2:

Performance risk	Physical risk	Financial risk	Psychosocial risk	Time risk
The product or store may not perform as desired and therefore will not deliver the benefits promised. Performance risk can be seen as a surrogate for $Overall\_perceived\_risk$ which results in a combination of other losses.	This refers to threats to the health or appearance of the consumer and to the physical and mental energy expended on shopping and effort-saving functionality of the products purchased.	This includes consumer concerns about how much goods are value for money as well as concerns about how much money might be wasted or lost if the product does not perform well. This also includes incidental costs accrued from the shopping experience, e.g. travelling costs, meals required and paying more than necessary.	This combines social risk resulting from friends and family thinking that a consumer has made a poor or inferior choice. The product might be perfectly alright but in the judgement of others it is imperfect in some way.	This refers to the amount of time required to purchase the product or the time lost as a result of product or service failure.

Table 4.1. List of risks factors affecting overall perceived risk, based on (Mitchell 1998)

In addition, Mitchell (1998) considers product-related factors, personal factors and situational factors as affecting risk perception. These are given in Table 4.2. below:

Product-related factors	Personal factors	Situational factors
1. Channel risk – i.e. consumers perceive a higher risk when ordering from places other than a normal high street retailer (Cox and Rich (1964); Gillet (1976). However, channel risk can also be product dependent. I.e. consumers feel different about where they buy a particular product. 2. Generic versus branded product risk – i.e. customers perceive the greatest performance risk with generic products and the highest financial risk with national brands. 3. Product usage time – i.e. risk perception increases with product usage time. e.g. In the CFSC chilled products have a limited time before they are safe to eat, which means that the risk increases the closer one gets to the product's use by date. 4. Product/service risk – i.e. that services are perceived as riskier than products, due to factors such as heterogeneity, perishability, inseparability and intangibility. 5. Country of origin – i.e. consumers perceive more risk in buying products made abroad by US firms than in buying products made by US firms in the USA.	1. Age – although older people are more risk-averse, it is more difficult to remove the influences of other age-related circumstances, e.g. experience, family responsibilities, financial situation, illnesses, etc. 2. Gender – i.e. if a male is the first to adopt a new product, he is seen as an innovator and risk-taker, but to imply he is a risk-taker is to imply he sees and appreciates risk in the environment which may not be true. 3. Socio-economic class – the effects of social class on risk perception remains unclear and it may be that, like gender, social class exerts its effects indirectly through differences in product experience, self-confidence or financial resources. 4. Inter-country differences – increases in tourism and international business travel mean more non-nationals consuming products while visiting countries. 5. Psychological traits – "high-risk perceivers" limit their product choices to a few alternatives and would rather exclude viable alternatives than risk a poor selection.	1. Group discussion – i.e. consumers are more willing to accept greater risk during or after discussion with other people than as individuals. For most grocery products it is therefore worthwhile for the retailer to initiate discussion free trial, or promotional activities. 2. Involvement – i.e. consumer involvement and perceived risk are positively correlated. The more consumers are involved with their grocery shopping the greater will be the retailer's need to assess their risk perceptions. Those on low incomes, and those who must be careful about what they eat (i.e. food allergies, health reasons) especially fall under this category.

Table 4.2. Additional risk factors affecting customer perception, based on (Mitchell 1998).

However, Mitchell also states that customers are either “risk averse” where the outcome is “generally good”, or else “risk seeking” where the outcome is “poor” (Mitchell 1999, 172). This means that each of the risk factors carries a weighting in the Cunningham equation, which shifts the threshold either towards pure uncertainty or towards pure adversity.

Jones (1999) presents an alternative reading of the Cunningham equation. Accordingly, each decision we make is based on two components: environmental demands (i.e. positive and negative incentives) and bounds on adaptability in the given decision-making situation (Jones 1999, 298). In an ideal situation a rational choice should be able to specify environmental incentives and be able to predict decisions based on those incentives. However, in practice we will only ever have a limited understanding of the environment, which in turn implies that any decisions we make must be based upon limited or uncertain data.

It follows that what Jones (1999) calls “environmental demands” Mitchell calls “uncertainty”. This is because the commercial environment in a perpetual state of flux. Similarly, what Jones (1999) calls “bounds on adaptability” Mitchell calls “adverse consequences”. Therefore, we can also express what Jones (1999) calls “random error” by considering whether or not customer decisions are weighted towards “risk aversion” or “risk seeking”. In this context “random error” must then be thought of in terms of Mitchell’s perceived risk factors, which implies that subliminally people are drawn to adversity. In other words, because the commercial environment changes continuously, what may have been a sensible purchase “yesterday” is not necessarily a sensible purchase “today”. A customer may continue to purchase a product out of loyalty when it is no longer commercially viable for the company to sell or make it.

4.10. Conclusions

This chapter introduced DEA as a technique for providing a measure of data efficiency within the context of incomplete or imperfect game environments. However, before introducing DEA it has engaged with a number of concepts related to uncertainty and Gödel's theorems of formal undecidability. Accordingly, it has also discussed the difference between determinate and indeterminate data, and why Dempster-Shafer theory is inappropriate when dealing with problems of this kind. In turn, this has led to the development of the "bounded rational" DEA model or the uncertain DEA model, which is based upon the entropic model for free energy within a thermodynamic system. Finally it introduced the Cunningham equation and demonstrated that it can be modelled as a DEA equation, as well as categorising the many risk factors which contribute to the overall perceived risk. Monitoring of data streams within incomplete or uncertain data is then possible by setting a threshold level by which the DMU is said to be efficient or inefficient. Indeed, if we consider the basic game theory model equilibrium (from equation 4.39)

$$\max_i \sum_{j=1}^{n} a_{ij} y_j^* = \min_j \sum_{i=1}^{m} a_{ij} x_i^* = v$$

we can modify this equilibrium into a DEA model, such that we have an effective benchmarking tool for any of the issues identified within the CFSC.

Chapter Five – Measuring and Improving the Performance of the Supply Chain Model

5.1. Introduction

This chapter will discuss methods to measure and improve the performance of the existing supply chain model. After anticipating the most likely areas where uncertainty is likely to be introduced into the supply chain model, this chapter will discuss the SCOR model (Stewart 1997). However, due to the many uncertainties which the CFSC contains, several reasons have been identified why the SCOR model is inadequate when applied to the CFSC. Hence, this chapter examines alternative models proposed by Shashi and Singh (2015), and by Joshi et al (2011), both of which were developed for use within the CFSC. The structure of this chapter is given in figure 5.1. below:

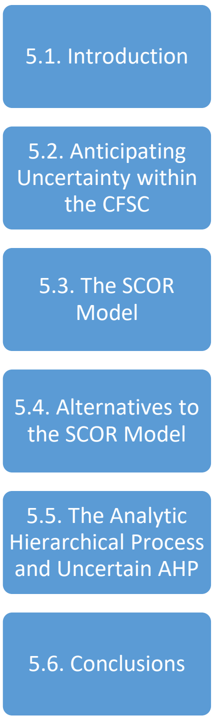

Figure 5.1. to illustrate the structure of Chapter Five.

5.2. Anticipating Uncertainty

Rodgers (2011) suggests four areas of study in relation to performance metrics where uncertainty is likely to be introduced into the supply chain. These are: technological innovation, process design, new product development and risk management. Within these four areas, Rodgers provides some possible sub-topics of study as follows:

1. Technological innovation – equipment design, new system development, testing equipment performance – food quality outcomes and resource consumption, consumer and organisational behaviour;
2. Process design – new food service systems, process optimisation, interaction between people and processes;
3. Product development – novel preparation techniques and methods, sensory evaluation and shelf life testing, consumer studies;
4. Risk management – design of risk management systems, quantitative risk assessment, behavioural aspects of risk assessment (Rodgers 2011, 477).

However, before we can consider how these topics might be implemented we should also consider that the leading model for supply chain performance metrics is the SCOR model.

5.3. The SCOR Model

Stewart (1995) presents a framework for describing business processes: Plan, Source, Make, Deliver, and suggests that the key performance indicators (KPIs) should be:

1. Delivery performance
2. Flexibility and responsiveness
3. Logistics cost
4. Asset management

This model was adopted in 1996 in America by the Supply Chain Council (Stewart 1997) as the standard which has subsequently been developed into the Supply Chain operations Reference (SCOR) model. The SCOR model is itself made up of three parts:

1. A modelling tool which uses standardised processes as building blocks;
2. A set of KPIs;
3. A benchmarking tool where companies can compare KPIs with other companies (Persson 2011, 289).

Accordingly, the four levels, Plan, Source, Make and Deliver, are redefined in accordance with four levels of detail:

> Level 1 – the scope (i.e. “Plan” or strategic) level, where the scope, context, geographies, segments and products are determined;
>
> Level 2 – the configuration (i.e. “Source” or tactical) level, where the major configurations within geographies, segments and products are identified;
>
> Level 3 – the business activities (i.e. “Make” or operational) level, which provides the company with information necessary to plan and set goals for its supply chain improvements;
>
> Level 4 – the implementation level (i.e. “Deliver”), in terms of specific supply chain improvements. These are specific to the company and therefore are not defined within the industry standard model.

However, the assumption is that the SCOR model is sufficiently robust. Stone (2011) lists a number of identified weaknesses with the existing SCOR model, which include:

1. A lack of network-orientated logistics-controlling mechanism, being oriented towards local performance maximisation as opposed to a supply chain wide orientation (Bullinger et al 2002). This is a consequence of there being no comprehensive supply chain wide performance framework.
2. The current model does not address sales and marketing, product development, research and development and some elements of post-delivery customer support (Kasi 2005).
3. The target setting does not consider multiple perspectives of the problem owners and neither does it readily accommodate the time phasing of objectives (Stone 2011, 66).

The SCOR model is however the most developed supply chain performance measurement framework in widespread operation (Stone 2011, 67).

Gunasekaran et al (2001) and Gunasekaran et al (2004) develop a framework for measuring the strategic, tactical and operational level performance of a supply chain. Accordingly, performance measures and metrics are studied in the following contexts:

1. By understanding financial and non-financial (i.e. operational) performance measures in a balanced framework.
2. By concentrating on fewer, balanced performance measures rather than having a large number of measures which keep being added to.
3. By assigning metrics at the strategic, tactical and operational levels.

Hence, any study of performance metrics should adopt a balanced approach and consider the entire supply chain.

Chae (2009) lists performance metrics as being of “primary” or “secondary” importance within the meta-levels of the SCOR model. The main assumption is that a company’s supply chain relies upon forecasting and order information, rather than order information only, which in turn allows for push-based and pull-based planning.

Tako et al (2012) rank the issues in logistics and supply chain management (LSCM) in order of transition from the “Strategic” to the “Tactical/Operational” as follows:

Strategic	Supply chain structure (SCS)
	Process redesign (BPR)
	Supplier selection (SS)
	Facilities/ Capacity planning (FCP)
	Supply chain integration (SCI)
	Information sharing (ISH)
	Bullwhip effect (BE)
	Reverse logistics (RL)
	Replenishment control policies (RCP)
	Supply chain optimisation (SCO)
	Cost reduction (CR)
	System performance (SP)
	Inventory planning/management (IPM)
	Planning & forecasting demand (PFD)
	Production planning & scheduling (PP-SCH)
	Distribution & transportation planning (DTP)
Tactical/Operational	Dispatching Rules (DR)

Figure 5.2. Diagram based on (Tako et al 2012, 805) to illustrate the transition of performance metrics from the strategic level to the tactical and operational levels.

However, it is difficult to classify logistics and supply chain management (LSCM) issues as being strategic, tactical or operational because a simulation study might address overlapping decision levels (Tako et al 2012, 805). In addition, a detailed distinction of issues between the strategic and the operational/tactical levels has not been found in the literature (ibid.), which raises questions concerning the strategic, tactical and operational levels of the SCOR model.

Chae (2009) suggests that many companies have “very little understanding” of how to define key performance indicators (KPIs) for their supply chain model (Chae 2009, 3). Successful supply chain management depends upon closing the gap between the planning and execution stages (Chae 2009, 2), which also calls the strategic, tactical and operational levels of the SCOR model into question.

Vlajic (2010) informs that there is a lack of integral framework that guides companies managing disturbances and designing robust supply chains, whilst Vlajic et al (2012) discuss the need for an integrated framework to support the analysis and design of robust food chains.

Chan et al (2003) states that performance measurement has not received adequate attention in the literature, whilst Shepard and Gunter (2006) claim that significant gaps exist within the literature.

5.4. Alternatives to the SCOR Model

Shashi and Singh (2015) state that “SCM is not only making and delivering, but is also an intangible strategy to tackle the dense competitive arena” (Shashi and Singh 2015, 202). In developing Farley (1997), Shashi and Singh (2015) suggest that SCM focuses on how firms use their supplier’s processes, technology, capability to enhance a competitive advantage, the coordination of the manufacturing, logistics and materials management functions within an organisation (ibid.) and that the three nodal points of this objective are:

1. How to improve overall supply chain performance;
2. How to gain a competitive advantage;
3. How to reduce supply chain losses for better supply chain performance (ibid.).

Shashi and Singh (2015) also state that many of the structural relationships between factors have been missed within the existing literature (ibid.). Whilst not explicitly attacking the SCOR model the implication is that the strategic, tactical and operational levels of the SCOR model do not clearly address the complex structural relationships between factors. Based on this reasoning Shashi and Singh (2015) propose an alternative a model based on twenty five variables, which are classified into four groups:

1. The managerial metrics (having ten variables);
2. The logistics metrics (having eight variables);
3. The relationships metrics (having four variables);
4. The innovation metrics (having three variables).

Hence, the twenty five total variables can be categorised under these headings. For illustrative purposes, the structure of these metrics is given in Figure 5.3 below.

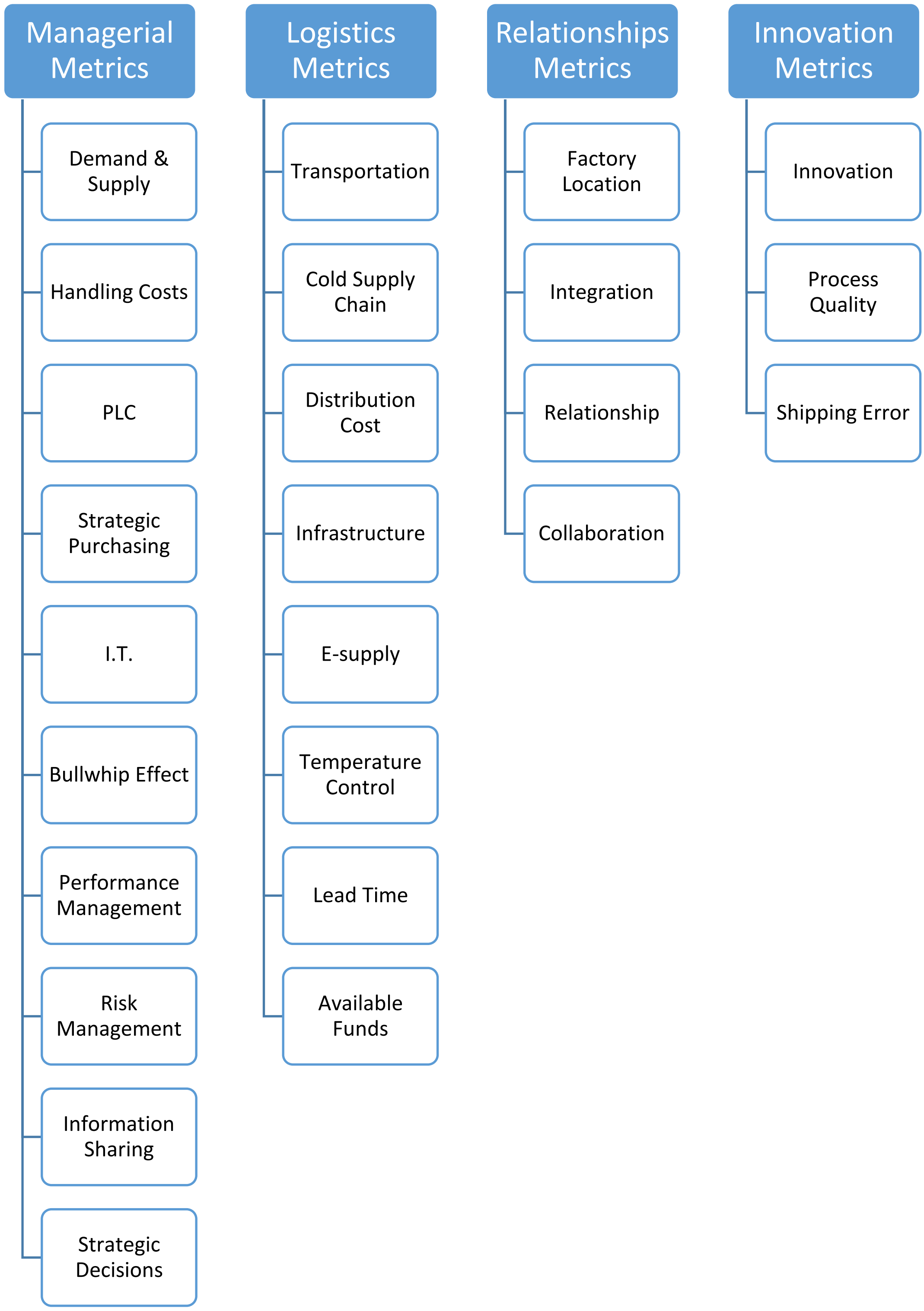

Figure 5.3. An illustration of the hierarchical structure based upon the four metrics of Managerial, Logistics, Relationships and Innovation, developed from the model proposed by Shashi and Singh (2015).

It is also clear that Shashi and Singh (2015) do not discuss the strategic, tactical and operational levels of the supply chain explicitly, and neither do they consider the stages plan, source, make and deliver for similar reasons. Instead, they suggest that supply chain performance can be effectively improved through effective planning, forecasting and control (Shashi and Sing 2015, 199). This is in agreement with Chae (2009) who states that a company's supply chain relies upon forecasting and order information, rather than order information only (as previously discussed). Given the complexity of the CFSC, this becomes evident by virtue of the strategic, tactical and operational levels of the supply chain becoming increasingly ambiguous, as previously pointed out by Tako et al (2012), because a simulation study might address overlapping decision levels.

Joshi et al (2011) discuss a benchmarking framework that evaluates the effectiveness of a company's key performance factors (KPFs) against those of its competitors within the Indian cold chain. This is based on a hybrid Delphi-AHP-TOPSIS method. Accordingly, Delphi is an iterative process by which a literature search is developed into a listing of KPFs in relation with expert opinion, which in turn leads to brainstorming, semi-structured questionnaires and interviews. However, establishing a "league table" of KPFs is a powerful technique for establishing which areas of the business are under performing, as well as establishing new areas for business development.

AHP stands for Analytic Hierarchy Process. Accordingly, AHP is used as a method for structuring and ordering complex decisions into a structured hierarchy. It was first proposed by Saaty (1980) and is based on the following three parts:

1. Identifying and organising decision objectives, criteria, constraints and alternatives into a hierarchy;

2. Evaluating pairwise comparisons between relevant elements at each level of the hierarchy;
3. Synthesis using the solution algorithm of the results of the pairwise comparisons over all levels of the hierarchy (Saaty 1988, 110).

In addition, AHP provides the relative importance of alternative courses of action.

By contrast, TOPSIS stands for Technique for Order Preference by Similarity to Ideal Solution. It is based on the principle that the chosen alternative should have the shortest geometric distance from the positive ideal solution.

However, Joshi et al (2011)'s approach also does not immediately suggest the strategic, tactical and operational levels of the SCOR model. Instead, the model is based upon the following KPI: Cost, Quality and safety, Service level, Traceability, Return on asset, Innovativeness, Relationship, which are then broken down into further sub-factors. These factors are further broken down and assessed in relation to the seven requirements of the Delphi method, which are: Effectiveness, Payback Period, Added Cost, Added Time, Capability, Adhesion with Existing System, Top Management Willingness and Other Constraints.

By comparison, fuzzy AHP or FAHP is proposed by Elgazzar et al (2011) and Kunadhamraks and Hanaoka (2008), in which pair-wise comparisons in the judgement matrix are fuzzy numbers that are modified by the designer's emphasis (Elgazzar et al 2011, 174). Elgazzar et al (2011) propose linking FAHP with SCOR as a means of overcoming the limitations of both techniques.

However, Liu (2016) is sceptical of fuzzy set theory since it is "not self-consistent" within mathematics (Liu 2016, 485). Instead, Liu proposes that fuzzy set theory should be replaced by uncertain set theory. This would infer that uncertain AHP may be a more reliable approach to be developed. This would mean that individual processes can be ranked according to their measure of uncertainty.

It follows that in adopting Shashi and Singh (2015)'s approach using the four metrics – Managerial, Logistical, Relationships and Innovation – some variation of the AHP technique could be used in order to determine what the relevant performance factors should be. Hence, an improved solution would be the representation of Shashi and Singh (2015)'s four metrics combined with AHP or the hybrid Delphi-AHP-TOPSIS. From the material on DEA discussed in Chapter Four it should also be possible to link AHP with DEA, such that AHP can resolve the hierarchical importance of each metric and DEA can be used to quantify or establish a threshold for each metric.

Kurien and Qureshi (2011) also suggest that DEA can be used as a performance measurement technique. However, Kurien and Qureshi (2011) are critical of DEA within this application since there is a limit upon the number of relationships that can be analysed between input and output units (Kurien and Quereshi 2011, 27).

Nevertheless, working within this limit suggests that the "bounded rational" or uncertain hybrid AHP-DEA model would be the best compromise. However, in order to implement this kind of solution we must first understand the AHP technique and identify its main limitations.

5.5. The Analytic Hierarchy Process (AHP) and Uncertain AHP

Having briefly mentioned the AHP as a decision making tool, this section will provide an overview of the technique and will demonstrate how an uncertain AHP or "bounded rational" AHP might be developed from it. The basic steps of AHP as given by Saaty (1980) are as follows:

1. State the problem;
2. Broaden the objectives of the problem, or consider all actors, objectives and its outcome;
3. Identify the criteria that influence the behaviour;
4. Structure the problem in a hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives;
5. Compare each element in the corresponding level and calibrate them on the numerical scale. This requires $n(n-1)/2$ comparisons, where n is the number of elements with the consideration that diagonal elements are equal or 1 and the other elements will simply be the reciprocals of the earlier comparisons;
6. Perform calculations to find the maximum Eigen value (λ_{max}), consistency index (CI), consistency ratio (CR) and normalised values for each criteria/alternative;
7. If λ_{max}, CI and CR are satisfactory then a decision is taken based on the normalised values; else the procedure is repeated until these values lie within the range.

These steps are formalised as illustrated in Figure 5.3 as given by Wang et al (2008):

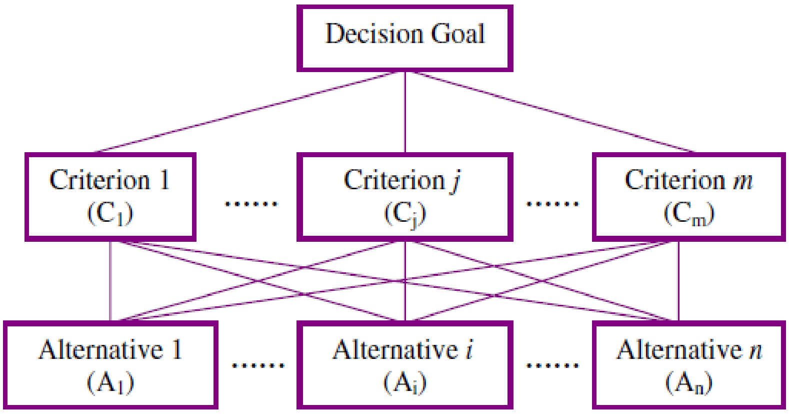

Figure 5.3. Diagram of the analytical hierarchical process based on Wang et al (2008).

Let $C_1, \dots, C_m$ be m decision criteria and $W = (w_1, \dots, w_m)^T$ be their normalised importance weight vector, which is to be determined by using pairwise comparisons and satisfies the normalization condition $\sum_{j=1}^{m} w_j = 1$ with $w_j \geq 0$ for $j = 1, \dots, m$. The pairwise comparisons between m decision criteria are assessed on a scale of 1 – 9 in terms of their importance.

Importance Intensity	**Definition**
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
Reciprocals	Reciprocals for inverse comparison

Table 5.1.Table of weightings used to form the comparison matrix, based on Wang et al (2008)

However, as can be seen from Table 5.1., the use of importance weightings of 1 – 9 leads to ambiguities over the values “2, 4, 6 and 8”. Hence, if the AHP analysis returned an importance weighting of, say, “8”, then it resides between “very strong importance” and “extreme importance”, which in turn implies that “extreme importance” of that metric is potentially ambiguous. Hence, for these kinds of ambiguities it follows that an “upper” and “lower” estimate for each importance metric might be taken.

Within conventional AHP the importance weightings are then used to form a $m \times m$ pairwise comparison matrix as follows:

$$A = (a_{ij})_{m\times m} = \begin{array}{c|cccc} & C_1 & C_2 & \dots & C_m \\ C_1 & a_{11} & a_{12} & \dots & a_{1m} \\ C_2 & a_{21} & a_{22} & \dots & a_{2m} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ C_m & a_{m1} & a_{m2} & \dots & a_{mm} \end{array}$$

(Equation 5.1)

Where a_{ij} represents a quantified judgement on w_i/w_j with $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$ for $i,j = 1, \dots, m$. If the pairwise comparison matrix $A = (a_{ij})_{m\times m}$ satisfies $a_{ij} = a_{ik}a_{kj}$ for $i,j,k = 1, \dots, m$ then A is perfectly consistent; otherwise it is inconsistent.

The weight vector W is determined by solving the following characteristic equation:

$$AW = \lambda_{max}W \qquad \text{(Equation 5.2)}$$

Where λ_{max} is the largest eigenvalue of matrix A.

The consistency index (CI) is given by

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \qquad \text{(Equation 5.3)}$$

The consistency ratio is given by dividing the CI by the random inconsistency (RI) index

$$CR = \frac{CI}{RI} \qquad \text{(Equation 5.3)}$$

Saaty (1987) states how the RI is derived from a sample size of 500 of a randomly generated reciprocal matrix using the scale 1/9, 1/8,…,l,…,8,9 to see if it is about 0.10 or less. If the RI is not ≤ 0.10 the problem needs to be revised. Saaty (1987) gives the following table as an indicator of typical RI values:

n	1	2	3	4	5	6	7	8	9	10
Random consistency index (RI)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 5.2. Table of RI values as given by Saaty (1987).

Decision alternatives are pairwise compared with respect to each decision. After the weights of the decision criteria and decision alternatives with respect to each criterion are obtained the overall weight or priority of each decision alternative with respect to the decision goal is generated using the simple additive weighting (SAW) method (Hwang & Yoon 1981):

$$W_{A_i} = \sum_{j=1}^{m} w_{ij} w_j \, , \quad for\ i = 1, \dots, n \qquad \text{(Equation 5.4)}$$

Where $w_j (j = 1, \dots, m)$ are the weights of the decision criteria, $w_{ij} (i = 1, \dots, n)$ are the weights of the decision alternatives with respect to the criterion j and $W_{A_i} (i = 1, \dots, n)$ are the overall weights of the decision alternatives. A decision can then be made based on the overall weights of the decision alternatives.

However, we recognise immediately that this model is derivative of the basic game theory model equilibrium

$$\max_i \sum_{j=1}^{n} a_{ij} y_j^* = \min_j \sum_{i=1}^{m} a_{ij} x_i^* = v \qquad \text{(Equation 5.5)}$$

Hence, we can amend the SAW method to provide an upper and lower measure of belief degree, for when importance weightings are intermediate. Hence, the order of priority of each performance metric can be adjusted, given that their importance weighting might reside between two values.

5.6. Conclusions

This chapter has discussed methods to measure and improve the performance of the CFSC model. Whilst the SCOR model is the most developed supply chain performance measurement framework in widespread operation, there are a number of limitations associated with it. In particular, because the CFSC itself derives from many other supply chain networks, the strategic, tactical and operational levels of the SCOR model become increasingly ambiguous due to increasing complexity of supply chain interactions. However, from Shashi and Singh (2015) and Joshi et al (2011), we have demonstrated how it is possible to construct an alternative to the SCOR model. This alternative approach is based on a hybrid AHP-DEA model, or “bounded rational” AHP-DEA model, which proposes the best possible strategy based on limited or incomplete data.

Chapter Six – How Customer Demand Contributes to Food Losses and Waste

6.1. Introduction

One of the biggest issues that we have not yet addressed is the question of how customer demand might reduce Food Losses and Waste (FLW) if there was greater public awareness of the underlying sustainability issues. This chapter will seek to resolve this question by answering the following research questions:

1. How do we contextualise FLW within the wider context of sustainable systems?
2. What is meant by Sustainable Food Supply Chain Management (SFSCM)?
3. How might local food initiatives help to reduce FLW?
4. How has customer demand impacted upon SFSCM?
5. What can we learn from the rise of fast food?
6. What can we learn from recent food scandals and how might these be avoided?
7. What can we learn from the Slow Food Movement?
8. How might we develop the coffee shop model of selling ambience and social positioning as a means of improving customer demand for healthier food that has been produced through sustainable practices?

Accordingly, the structure of Chapter Nine is given in Figure 6.1. below

Figure 6.1. to illustrate the structure of Chapter Nine.

6.2. Contextualising FLW within the Wider Context of Sustainable Systems

In November 2012 the UN Committee on Food Security requested the High Level Panel of Experts on Food Security and Nutrition to conduct a survey into food losses and waste (FLW) within the context of sustainable systems. The revised June 2014 report (HLPE 2014) suggests that FLW can only really be reduced by improving transport, energy and market facilities, and that this can only be realistically achieved via a combination of Government action and initiative from the private sector.

FLW can be considered from either a waste-focused or a food-focused approach (HLPE 2014). By definition, a waste-focused approach is concerned with reducing wastage of all kinds, as well as reducing the costs involved in the treatment of waste and the non-edible parts of produce. However a food-focused approach is concerned with addressing why edible food is lost or discarded within the food chain.

FLW is considered on three levels:

1. Micro-level causes, in which every stage of the food supply chain is monitored;
2. Meso-level causes, which are structural causes based upon how well the different actors within the food supply chain work together. In this context it follows that the necessary infrastructure to support close working relationships between partners involved within the supply chain is of vital importance;
3. Macro-level causes, which are higher-level accounts of how FLW can be explained in by more systemic issues, such as the lack of sufficient policy to facilitate actors to work together effectively.

In order to reduce FLW at these three levels Table 6.1 is given, which illustrates effective strategies for eliminiating FLW at the micro, meso and macro levels:

Levels			
Categories	**Micro**	**Meso**	**Macro**
Investments	Private investment in production, postharvest, businesses and food services.	Financial mechanisms; Collective private investments; Public investments.	Support to financial mechanisms; Infrastructure; Enabling environment; Proper incentives.
Good Practices	Good practices in production and postharvest.	Capacity building; Training.	Support to capacity building; Multi-stakeholder incentives.
Behavioural Changes	Behavioural change in businesses and consumers.	Corporate social responsibility; Community and local engagement.	Raising awareness; Multi-stakeholder initiatives.
Coordination inside Food Chains		Food chain approach; Relationships with other actors in the food supply chain.	Enabling environment (i.e. contractual rules and incentives); Policies.
Valorisation of Food and By-products		Food processing; Valorisation of surplus foods and by-products.	Support and implementation of a hierarchy of uses.
Coordination of Policies and Actions			Policies; Multi-stakeholder initiatives.

Table 6.1 to show effective strategies for reducing FLW at the micro, meso and macro scale, based on the table given in (HLPE 2014, 57).

From this table it is clear that investments, good practices and behavioural change are required at all three levels. However, without effective multi-stakeholder policies and initiatives at the meso and macro levels, changes at the micro-level will be ineffective. This implies that we need to add an additional weighting to our models for FLW to compensate for losses at the meso and macro levels.

6.3. Pre-Harvest Losses

Pre-harvest factors are often overlooked. Whilst studies like Parfitt et al (2010) provide an overview of the stages of the food supply chain (i.e. harvesting, threshing, drying, storage, primary and secondary processing, product evaluation, packaging, marketing and distribution, post-consumer end of life), pre-harvest factors contribute to a failure to meet quality standards and lead to a high percentage of rejection of produce.

In addition, pre-harvest factors can greatly influence harvest yields and food quality (HLPE 2014, 41), which include:

1. Choice of crop varieties for the location and target market (i.e. certain types of farms may be localised to specific areas, whilst produce can only be sold if there is sufficient market and profit margins to make this economical);
2. Agronomic practices, including fertilisation, water management, pest/disease management, pruning, staking and bagging;
3. Biological factors and environmental factors (i.e. disease, soil, temperature, humidity, etc.).

The HLPE (2014) report also recommends four strategies for reducing FLW in its different contexts (HLPE 2014, 90), which are:

1. Gather information and data (i.e. agree on the scope of FLW definition, agree on protocols for FLW measurement, and collect the data and promote transparency and corporate responsibility at all levels);
2. Diagnose and develop strategies (i.e. identify FLW hotspots, the causes of FLW at all levels, solutions, costs and benefits for all actors, and decode upon an implementation path and plans of action – what to do effectively at actor level and concerted actions at the collective level);
3. Act, individually and collectively (i.e. raise awareness and support multi-stakeholder initiatives, roll out action plans, consider systemic developments, experiment and learn);
4. Coordinate policies to reduce FLW (i.e. establish an enabling environment, support capacity building, integrate FLW concerns within agricultural policies and development plans, develop and adapt other FLW policies, set FLW reduction targets).

In effect, this reasoning calls for a greater emphasis to be placed upon BTO management practices – that is, improved threshold levels at the pre-harvest phase so that farmers and growers are not overproducing. Hence, an effective Lean strategy would need to work in tandem with the HLPE (2014) recommendations. Similarly, improved information sharing between the pre- and post-harvest stages would effectively resolve issues such as food surpluses and food deficits. Accordingly, this would lead to a strategy of “growing what we do need rather than what we don’t need.”

6.4. Sustainable Food Supply Chain Management (SFSCM)

Soysal et al (2012) suggest that in the last two decades there has been a transition from a focus on traditional supply chain management (SCM) issues to food supply chain management (FSCM), and successively to sustainable food supply chain management (SFSCM). This concerns the balancing of ecological, economic and social impacts, which means that products need to be socially fair and environmentally friendly, as well as being produced efficiently, competitively and profitably. The major factors contributing to SFSCM are:

1. Raising consciousness of the importance of sustainable system dynamics;
2. Changing regulations set by governments that enact strict rules on food safety and sustainability issues.

The aim of these legislations is to ensure firms take necessary precautions against negative social and environmental impacts upon their operations. Companies operating within the agri-food sector are confronted by the following:

1. Accelerating environmental and social impact assessment policies and standards, including HACCP, BRC, or ISO22000;
2. Emerging concept of extended producer responsibility supporting the shift from "cradle to grave" to "cradle to cradle" pushed by governments or private institutions;
3. Increasing preoccupation within society to live well without compromising future generations' right to prosper.

However, Christopher (2011) suggests that "customers don't buy products, they buy benefits" (Christopher 2011, 6) to infer that products are purchased on the promise of what they will deliver. It follows that companies need to adopt a segmented approach. i.e., Benefits have differing levels of importance from customer to customer. Soysal et al (2012), Van der Vorst et al (2011) and Van der Vorst et al (2007) discuss the concept of Quality Controlled Logistics (QCL) which depends upon the availability of real time product quality information and the use of that information in advanced logistics decision making along the SC.

Soysal et al (2012) also mention the Kyoto Protocol which has set binding targets for industrialised countries as a recent step towards achieving sustainable development. Similarly, the EU and the consciousness of consumers towards environmental and societal issues have put pressure on companies to use sustainable practices. Similarly, the need to improve traceability has a growing impact upon FSCs. Consumers want more insight into production processes as well as what happens to the product as it moves through the SC.

Hunt et al (2005) list the key challenges facing supply networks in the agri-food sector:

1. More instances of multi-site manufacturing.
2. Increasingly cut-throat marketing channels.
3. The maturation of the world economy.
4. Heightened demand for local products.
5. Competitive pressures to provide exceptional customer service.
6. Quick, reliable delivery.
7. Commonality of turbulence and volatility in markets.
8. Time-to-market for new products.

It therefore follows that supply chains will need to be less complicated and increasingly agile if they are to continue. Hunt et al (2005) and Lambert and Cooper (2000) suggest that the successful operation of an integrated supply chain relies upon its information flows for it to be successful.

However, Yakovleva et al (2004), MAFF (1999), Wagner (1999) and Cowell and Parkinson (2003) suggest that the following trends will impact upon the sustainability of food supply chains within the UK food sector:

1. Rapid changes in technology;
2. Changes in markets and marketing strategies;
3. Changes in industrial infrastructure;
4. Globalisation of markets;
5. Changes in consumption patterns;
6. Evolution of consumer demands;
7. Increasing environmental concerns;
8. Concerns about food crises; and
9. Consolidation and reduction in the number of organisations at all stages in the system.

Yakovleva et al (2004) suggest that these trends are largely driven by changes in technology. They also state that food production and consumption is a target for public policy due to concerns about its unsustainability. Accordingly, the pursuit of economic growth has come at the expense of environmental and sociological issues.

We therefore need to consider a weighting for how much a given food product has been produced by both ethical and sustainable practices.

6.5. Local Food Initiatives

Our Mutual Food (Ritchie et al 2011) is a report commissioned by the One Planet Food project at the Falkland Centre for Stewardship in Fife, with the help of funding by the Esmée Fairburn Foundation. The report was commissioned with the following aims:

1. To provide advice and encouragement to local food initiatives, which involve communities in growing food themselves and source it from local producers.
2. To research and develop regional policies and projects promoting sustainable food systems.
3. To influence national food policy, linking issues of food security and sustainable food production in Scotland with wider issues of environmental and social justice.

The report also discusses the rise in food prices since 2007, together with the impact of the recession on the UK's poorest households and the shift in diets "away from vegetables, cereals and 'proper meals' towards snacks, fast foods and energy dense processed food" (Ritchie et al 2011, 7), which means that the UK population has been getting more obese and less healthy and that there has been an increase in long-term illness due to poor diets.

However, the main focus of the report the research question: Could Fife Feed Itself? (Ritchie et al 2011, 19). Although the question is answered in the affirmative the report draws attention to the dominance of supermarket chains in food retailing. Indeed, after a breakdown of the leading supermarket sale figures in Fife, the report states that "most of the supermarkets in Fife are less than 20 years old" (Ritchie et al 2011, 25). Based upon DEFRA statistics for "what we should eat" compared with "what we do eat" this reasoning is then used to support the hypothesis that food is regarded more as a product or commodity than it is for its nutritional value. To support this hypothesis a survey was conducted based upon the following questions:

1. Access to local shops and farms;
2. Shopping preferences:
    a. Cost;
    b. Choice and range of foods;
    c. Convenience;
    d. Quantities;
3. Local food and provenance;
4. Food culture, health and the environment.

Based upon the results of this survey the report recommends “that Fife (and other regions) should implement a long-term, integrated policy to strengthen the local food system”, which “will operate autonomously alongside the dominant food system, offering an increasingly credible alternative” (Ritchie et al 2011, 37). Here it is clear that the report proposes a solution “alongside the dominant food system”. This strategy is informed by four proposed strategies:

1. Changing how we eat
2. Changing how we farm
3. Changing the food economy
4. Changing Government policy

However, “changing how we eat” also includes “changing what we eat”, and the Fife Diet initiative followers pledge to “eat local, eat less meat, eat more organic, reduce food waste and to compost more" (Ritchie et al 2011, 41) which could be taken as an over-idealised "road to good intentions" pledge. Yet rather than rigidly imposing the idea that the Scottish diet is generally poor, the recommendation is that the "Fife Diet, Slow Food and other local eating experiments demonstrate growing public awareness of food choices, and support people to make changes as part of a community (on-line or face to face)" (ibid.).

Positive results from the report suggest that those who follows the Fife Diet programme had reduced their carbon footprint from food by as much as 27%, whilst some members had reduced their meat consumption to less than half the UK average (ibid.).

The report also explains why eating less meat is "better" for consumers and the environment:

1. Grass-fed beef and lamb lock-up more greenhouse gas emissions than they produce;
2. It provides better systems for pig and poultry production, where animals can have better lives before they are slaughtered;
3. It reduces the need to import GM soya beans for animal feed, as well as reducing the overall amount of meat (i.e. 40% of consumption) that is imported into the UK each year;
4. It will improve our overall quality of health (ibid.).

The report also proposes some of the benefits in choosing organic products, which include:

1. Higher animal welfare standards;
2. Greater biodiversity;
3. No pesticides, therefore no residues;
4. Very few additives are allowed in the food;

5. No chemical nitrogen is used, which reduces the carbon footprint of production, negative impacts upon soil quality and water pollution risks (Ritchie et al 2011, 41, 42).

In addition, sourcing local suppliers also reduces transportation costs and importation of food produce, which in effect reduces the carbon footprints as well as the number of control points within the supply chain model.

The report also examines the supply-chain model for six European countries – farmers/producers, suppliers, semi-manufacturers, manufacturers, buying desks, supermarket formats, outlets, customers, consumers – and illustrates that the majority of the power resides with buying desks and supermarket formats. As such there is a predicted "asymmetry of risk" between small producers and consumers (Ritchie et al 2011, 43).

From here the report proposes six recommendations for Fife Council:

7. Support "grow your own" and community growing projects;
8. Build capacity for mutual food initiatives;
9. Support local food systems through joint public procurement;
10. Support local food training and exercise;
11. Recycle soil nutrients;
12. Help farmers produce and market more sustainable food (Ritchie et al 2011, 45 – 54).

The report closes with "Implications for a National Food Policy" to infer how the "Many to Many" (M2M) model could be developed nationally (Ritchie et al 2011, 43). Studies of this kind are then highly informative as to how FLW can be reduced, how generally poor diets can be improved, how local businesses and suppliers can work more closely together, and of course how a change in consumer demand for the food we enjoy can drastically alter the structure of existing supply chain models.

6.6. The Impact of Customer Demand upon SFSCM

Burch and Lawrence (2005) discuss how there has been a strong resistance towards customer pull in Europe and North America because retail outlets initially existed to sell manufacturers' products:

> This situation began to be transformed in the US and Europe from the 1960s. The fundamental social and economic changes occurring in post-war Europe and North America – in particular, the demand for, and the mass consumption of, a range of high quality products – led to a reconfiguration of the manufacturer-dominated supply chain (Burch and Lawrence 2005, 1).

This means that, especially in Europe and North America, the concept of a pure pull system in the agri-food sector is a relatively new concept. We can then perceive why the implementation of pull-driven supply chains has been slow, since this means a breaking with the tradition upon which the "manufacturer-dominated" approaches were founded.

In contrasting Fearne et al (2001) with Burch and Lawrence (2005) we can begin to chart the evolution of the modern supermarket supply chain, and therefore how the modern agri-food supply chain has needed to adapt with changing consumer demand patterns. Fearne et al (2001) indicate how the first self-service food store was opened in

1916 by Clarence Saunders (Fearne et al 2001, 4). This was in actuality the first Piggly Wiggly store in Memphis, Tenessee[1]. This would imply that customer demand has always been central to the evolution of the agri-food chain, but that each advance has only occurred when the technology was available to enable customer choice.

In addition, the literature points to two main reasons for the apparent shift in power from "push" to "pull" strategies:

1. The emergence of a "monopsony" in distribution where a large number of food processing companies are forced to sell their products to a limited number of globally-focused retailers who exercise enormous purchasing power in an increasingly concentrated market
2. The growing significance of supermarket "own-brand" products which have come to compete with the branded products of the established food manufacturing companies (Burch and Lawrence 2005, 1).

The first of these is in accordance with Fearne et al (2001). A "monopsony" literally means "single purchaser", which reflects the manner in which a handful of supermarket chains have come to dominate the food supply chain. However, most participants in the supply chain "want to exercise market and supply chain power to extract value from upstream suppliers, but deny their own downstream buyers from exercising the same market and supply chain power to extract value from themselves" (Burch and Lawrence 2005, 3).

One of the main consequences of this need to "exercise market and supply chain power" is in the rise in popularity of supermarket own-brand convenience foods. Whilst own-brand foods became more widespread during the 1970s, they were marketed as "low-

[1] See http://www.pigglywiggly.com/about-us

cost alternatives” to “premium” brands, “even though they were usually made by the same food manufacturing companies that sold goods under their own proprietary brand” (Burch and Lawrence 2005, 1). Yet over the past forty years supermarket own-brand products have “moved beyond imitation” to be at the leading edge of meeting customer demand. Chilled meals, convenience foods, prepared fresh foods, snacks and other product lines intended for “flexieating” have emerged through the supermarket chains “which the traditional brand manufacturers are not well-placed to satisfy” (Burch and Lawrence 2005, 2). This means that many major food processing companies are supplying and marketing purely supermarket own brands, which in turn is transforming the way in which the agri-food chain operates. The most logical progression of this scenario would be the transformation of supermarkets into “food outlets” where customers can pre-order exactly what they want when they want it.

6.7. The Rise of Fast Food

Eric Schlosser (2012) makes the connection between the rise of “fast” food and the rise of the automobile as the dominant mode of transport in the 1950s. In particular, the Interstate Highway Act of 1956, led to the construction of “46,000 miles of road” (Schlosser 2012, 22). The implication is then of a cultural shift towards speed to reflect the change of pace brought about by the new highways. Hence, “convenience” is perceived as a benefit because the pace of life is perceived as being increasingly faster, which in turn has created the myth that we do not have enough time to prepare, eat and enjoy our food.

However, Schlosser also indicates two further reasons why the popularity of fast food rose dramatically:

1. "The birth of the fast food industry coincided with Eisenhower-era glorifications of technology" (Schlosser 2012, 6). The implication here is that because "fast food chains still embrace a boundless faith in science – and as a result have changed not just what Americans eat, but how it is made" (ibid.) an acceptance of fast food and convenience food is a part of a wider acceptance of technology. In this sense, "convenience" food in its many contexts must also be perceived in relation to the technological innovation behind many "labour saving" consumer items we take for granted.
2. "A hamburger and French fries became the quintessential American meal in the 1950s" (ibid.). Within this statement we also perceive a self-perpetuating cycle in which fast food is associated with 1950s America, but also that the 1950s was an era which was dominated by technological innovation and post War affluence. Given how Burch and Lawrence (2005) cite the 1960s as the era when the role of the retail sector began to transform into a customer-driven market rather than a manufacturer-driven one, we then have an additional myth of 1950s America as being on the cusp of a "true" customer-driven market.

However, we should also consider many of the innovations which the McDonald brothers and Ray Kroc introduced into food production and distribution. For example the Speedee Service System, pioneered by the McDonald brothers in 1948 meant that food items could be made very quickly after they were ordered by the customer – as much as each of the food items could be quickly assembled from simple, pre-prepared components. An additional credit that should be attributed to Ray Kroc is the standardisation of McDonald's processes; such that every burger and milkshake should taste the same regardless of whichever restaurant it was made and consumed. Similarly, portion sizes, cooking methods and times, as well as packaging were also standardised throughout all McDonald's restaurants. Indeed, Schlosser states that the one key word to describe the success of the McDonald's franchise is "uniformity", or rather that "chain stores strive to offer exactly the same product or service at numerous locations" (Schlosser 2012, 5).

However, "always and everywhere the same" can also imply a lack of variety and/or a lack of product innovation. Accordingly, given that McDonald's has become known as a chain of stores which primarily sells hamburgers, we discover a growing list of products which turned into commercial disasters. Some of these "failed" items include: the Cheddar Melt, the Big N' Tasty, the Angus Burger, the Big 33 or McJordan Special, the McDLT and the Triple Double Burger – none of which significantly diverted from the conventional hamburger concept (Bhasin 2011). However, the McLobster was discontinued in 1993 because $4.99 was considered too expensive for McDonald's regular customers, whilst McPizza was dropped in 1989 because it took twenty minutes to cook (ibid.).

One of the most surprising items to be withdrawn from McDonald's restaurants is the supersize menu. Although many people attribute the withdrawal of the McDonald's supersize menu to Morgan Spurlock's documentary film, *Supersize Me* (Dir. Spurlock 2004), in which Spurlock ate nothing but McDonald's food for a month and charted his weight gain and health deterioration, the official reason given was that supersizing only represented 0.1% of McDonald's total sales. However, according to a BBC News item dated 4th March 2004, a meal consisting of a supersized Coke (323 calories), supersized fries (486 calories) and a Big Mac (1,302 calories) would amount to an astonishing 2,111 calories consumed (BBC News 2004). Given that the recommended number of daily calories for women is 2,000 and for men is 2,500, this could only contribute to national obesity levels and its associated health issues.

6.8. Food Scandals – The Cost of Getting it Wrong

In discussing the 2013 horsemeat adulteration scandal, Felicity Lawrence states that economy burgers only need to have 60 – 65 per cent meat content by law, with only 47 per cent of the content coming from a cow (Lawrence 2013). Yet this 47 per cent “is allowed to contain fat, collagen, and connective tissue in the same proportions as they naturally occur in the cut being used” (ibid.). This means that a cut of beef brisket can be used which is on average, “32 per cent fat, 19 per cent connective tissue and 3 per cent collagen” (ibid.). In other words a beef burger does not have to contain any actual minced beef meat for it to be legally sold as a beef burger. The implication is that we have not placed enough value upon nutrition, taste, quality, authenticity and traceability.

In comparison to the horsemeat scandal, Christoph Strünck (2001) contrasts British and European handling of the BSE crisis (i.e. mad cow disease) in the 1990s with the American response. He contrasts the democratic accountability of British and American governments by stating how “US federal governments do not have a higher-level of policy making at their disposal to which they could shift responsibilities, let alone scapegoat” (Strünck 2001, 4). Accordingly, trade rivalries between Germany, France and Britain meant that the EU could be used as a scapegoat for the crisis. Secondly, the US system of food safety disperses responsibility over several agencies. Strünck argues that the competitive environment amongst multiple US food agencies was better equipped to deal with food safety challenges than the single British FSA. He also argues that multiple agencies are “less likely to be captured by organisation interests, because different agencies lead to more checks and balances within the government" (Strünck 2001, 5).

This issue has, at least in part, been dealt with by the formation of DEFRA (the Department for Environment, Food and Rural Affairs) in 2001 by the then Secretary of State for Environment, Food and Rural Affairs, Margaret Beckett, after the failure of the Ministry of Agriculture, Fisheries and Food (MAFF) to adequately deal with the spring and summer 2001 outbreak of foot and mouth disease. The MAFF was merged with a part of the Department of Environment, Transport and the Regions (DETR) to form DEFRA.

In addition, Strünck argues that the BSE crisis was "dealt with as a political issue and not a technical issue" on the basis that if it has been a technical issue "the EU could have seized power by pointing at its responsibility for the Common Internal Market" (Strünck 2001, 10). In classifying BSE as a political issue the crisis fell under "benign neglect" which meant that the British government was in charge, which then meant that it could subsequently blame the crisis on the EU.

However, despite the BSE crisis, the foot and mouth crisis and the horse meat scandal, there have been very few campaigns which actively seek to promote customer demand for nutritious food and drink per se. Whilst there have been campaigns, like Public Health England's (PHE) ongoing Change4Life campaigns to reduce the amount of sugar consumed in children's food, these campaigns are targeted more towards making substitutions to family shopping lists instead of encouraging public demand for healthy and nutritious food. The perceptions "food as commodity", "food as an additional expense to poor households" and "not enough time to prepare and eat nutritious food" remain unchallenged – that is, there is very little real challenge towards the consumption of "fast food", "convenience food" and "junk food". Given how it is the poorest members of society that have the worst diet, the challenge is perhaps more radical than encouraging shoppers to make like-for-like substitutions to their shopping lists. Rather, it is a case of re-educating the population as to what food is nutritionally beneficial.

6.9. Slow Food – A Matter of Good "Taste"

The Slow Food movement was officially founded in 1989 as "a global, grassroots organization", in order to "prevent the disappearance of local food cultures and traditions, counteract the rise of fast life and combat people's dwindling interest in the food they eat, where it comes from and how our food choices affect the world around us" (Slow Food 2016).

Slow Food embraces a philosophy defined by three words:

1. "Good" which means that food that is good quality, flavoursome and healthy;
2. "Clean" which means that production techniques do no harm to the environment;
3. "Fair" which means "accessible prices for consumers and fair conditions and pay for producers" (ibid).

Accordingly, the Slow Food movement seeks to add value in locating food production and consumption systems that are less harmful to the environment but also to people, yet endorsing the idea that the time taken to eat and enjoy food is a part of the taste experience.

In terms of customer "pull" however the demand for Slow Food can be shown to arise directly from an increasing awareness of "taste, biodiversity, the health of humans and animals, well-being and nature" (ibid.). It follows that a better awareness of where food has come from, together with the knowledge that it is less harmful to personal health, the environment and to animals, will contribute to the "taste" of Slow Food in a way which fast food can simply not achieve. Clearly, this philosophy is the antithesis to that which gave rise to the horsemeat scandal of 2013.

Hence, “taste” is the final stage in the supply chain “from farm to fork”, such that it embodies all of the culture and tradition of which that particular product signifies. However, the authors are keen to point out the added value to both the consumer and the producer which this would bring:

> When there are no apparent distinctions, it is because the differences have not been studied and described, not because they do not exist. In Italy in the 1960s, wine was red or white. Today a universe of different wines exists, which change according to the vine variety, the territory, winemaking techniques and ability of individual producers. Promoting diversity is fundamental to saving small-scale producers. Uniformity, flattening and superficiality (those who say “this product is the same everywhere”) favour producers of large quantities at the expense of quality. The fact that a product could be widespread over very large areas, often with the same name, does not mean that it is not at risk in each of the territories where it is traditionally prepared (Milano et al 2013b, 15).

On the question of distinctions (in this case between one variety of red wine and another) the most important aspect is consumer awareness. What the authors term “uniformity, flattening and superficiality” is therefore the enemy of customer choice. It also follows that without customer choice there is no conception of customer “pull” – or rather, that “pull” is increasingly limited – which in turn impacts upon the oversaturation of very similar products which are increasingly bland and therefore "tasteless".

Slow Food is then empowering as a concept in building dialogues between cultures, given that the one thing all people have in common is their enjoyment of food.

6.10. Selling Ambience and Social Positioning – The Latte Revolution

In comparison to fast food and the "convenience" food market of the supermarkets, Stephano Ponte (2001) discusses how the global coffee chain underwent a "latte revolution", where consumers could choose from "hundreds of combinations of coffee variety, origin, brewing and grinding methods, flavoring, packaging, social 'content,' and ambience" (Ponte 2001, 1099). With changing (relaxed) regulations concerning how coffee is imported across the global commodity chain (GCC) coffee became an almost entirely "pull" driven industry because of the consumer demand for it.

Although written in 2001, the main reason for the lasting success of the "latte revolution" is that "Coffee bar chains sell an ambience and a social positioning more than just 'good' coffee" (ibid.). This is attributed to what Ponte calls the ''Starbucks factor":

> The breakthrough that made Starbucks a stunning success was creating a café atmosphere where customers could hang out and consume an ''experience'' at a place that was neither home nor work. This happened at the same time

> as other consumer products moved from mass-production and marketing to being recast as more authentic, flavorful and healthy (Ponte 2001, 1111).

In comparison to local food initiatives like *Our Mutual Food* and the *Slow Food Manifesto*, we can also perceive a similar opportunity for a “food revolution”, where customers can experience a variety of foods which are healthy, ethically and sustainably sourced.

6.11. Discussion – the Modified Dissatisfaction Equation

We can now adapt the Ren et al (2013) equation for minimising the total dissatisfaction level, which we discussed in section 7.7.2. for losses at the meso and macro levels.

Firstly, $Required\ Cost$ is given as:

$$Required\ Cost = micro + meso + macro \qquad \text{(Equation 6.1)}$$

Accordingly, if we are only concerned with the required cost at the micro level then the weightings for $meso$ and $macro$ can be ignored. However, for reasons already cited in this chapter, we need to be aware of how these additional factors can affect the CFSC given that it derives from the much broader agri-food supply chain. Here we might also consider a penalty/reward system for sustainable practices at the three levels, micro, meso and macro.

Secondly, $Acceptable\ level\ of\ Wastage$ is given as:

$$Acceptable\ level\ of\ Wastage =$$

$$pre\_harvest + harvest + thresh + dry + store + proc_{prim} + proc_{sec}$$

$$+ evaluation + pack + market + dist \qquad \text{(Equation 6.2)}$$

In addition, we might also factor in consumer wastage, although this emerges after the distribution stage of the supply chain.

However, as with the values for $Required\ Cost$ we should also consider the model for $Acceptable\ level\ of\ Risks$ on the micro, meso and macro scales. Therefore:

$$Acceptable\ level\ of\ Risks = micro + meso + macro \quad \text{(Equation 6.3)}$$

Similarly, if we are only concerned with the micro scale, the weightings for meso and macro level risk can effectively be set to zero. However, these additional weightings would allow for risks such as crop damage, food adulteration (c.f. the horse-meat scandal) or other risks further up the food supply chain, to be considered.

6.12. Conclusions

This chapter has discussed some of the wider issues concerning FLW and has suggested strategies for how these issues might be better managed by adopting a Lean perspective. This reasoning has led to the construction of the modified dissatisfaction equation.

Chapter Seven – Research Methodology

7.1. Introduction

This chapter outlines the research methodology which will be used in this study. It begins with an overview of the research process and explains the philosophical considerations underlying the methodology. The structure of this chapter is given according to Figure 7.1 shown below

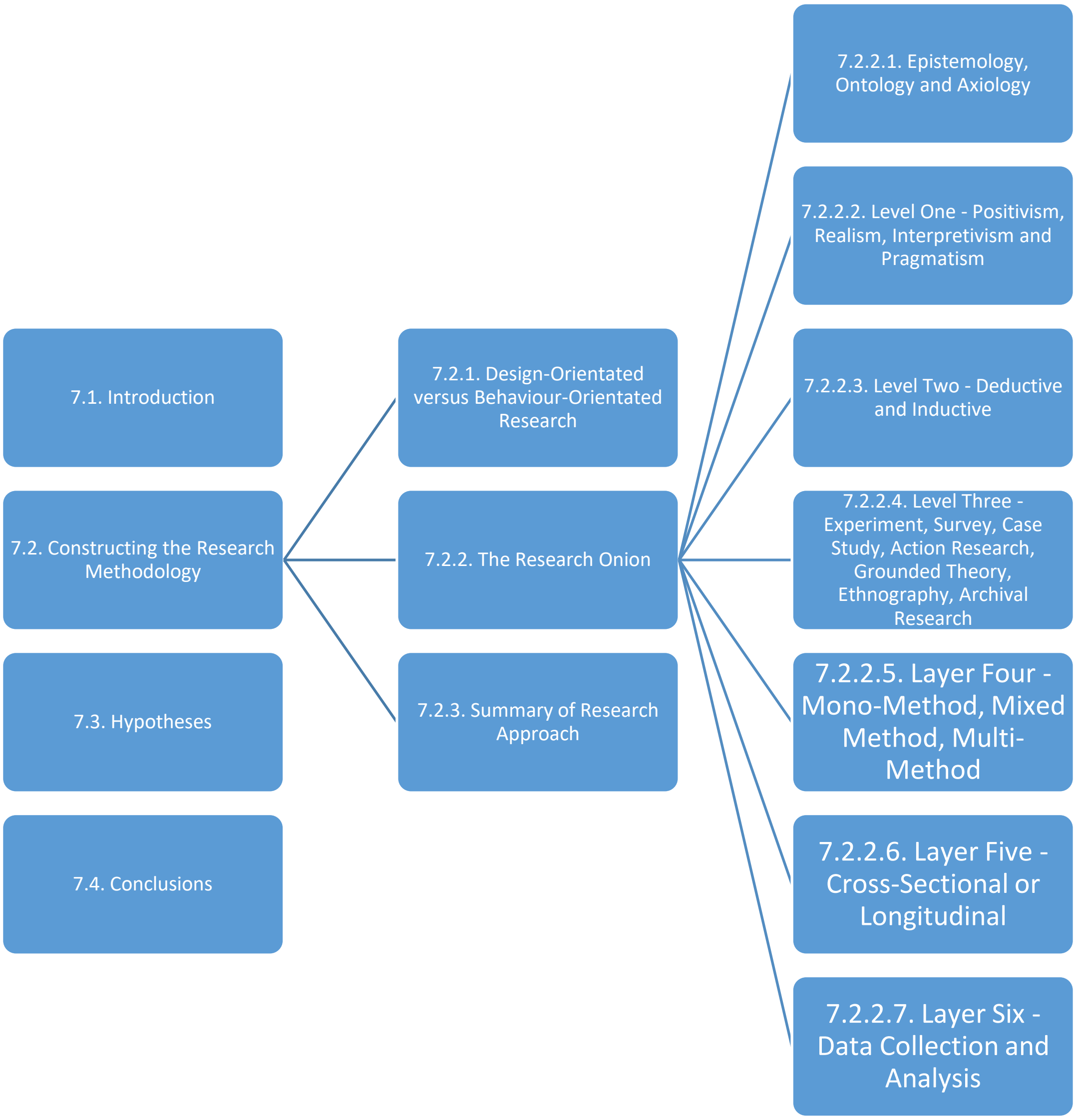

Figure 7.1. to illustrate the structure of Chapter Six.

7.2. Constructing the Research Methodology

There are two components involved in constructing the research methodology. The first is a discussion of design-orientated research versus behaviour-orientated research. The second is an overview of the technique known as the research onion.

7.2.1. Design-Orientated versus Behaviour-Orientated Research

Design-orientated research is concerned with the guidelines for the construction and operation of information systems, as well as bringing about innovation within the system, whilst behaviouristic research is concerned with the analysis of information systems as a phenomenon, as well as cause-effect relationships in the use of information systems (Hinkelmann and Witschel 2013). Figure 7.2 illustrates how artefacts provide utility whilst theories provide truth:

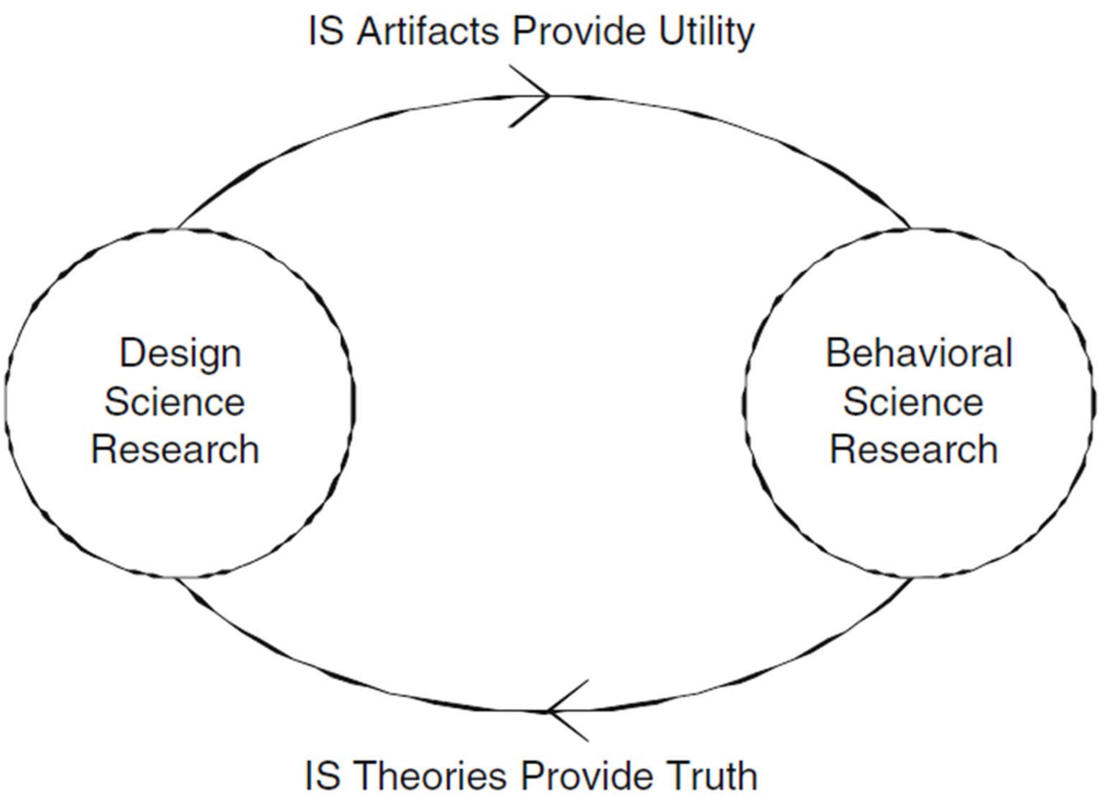

Figure 7.2. Design-orientated research versus behaviour-orientated research (Hinkelmann and Witschel 2013, 11; Hevner and Chatterjee 2010)

By definition, customer spending habits must be behaviour-orientated, whilst models of the chilled food supply chain must be design-orientated in order to meet customer demand. It follows that the chilled food supply chain cannot be studied without understanding customer behaviour patterns.

7.2.2. The Research Onion

Since the research consists of both design-orientated and behaviour-orientated research, the research onion technique as proposed by Saunders et al (2007) is considered as a means of locating the most effective research methodology. Figure 7.3 illustrates the revised model of the research onion as given by Saunders et al (2009).

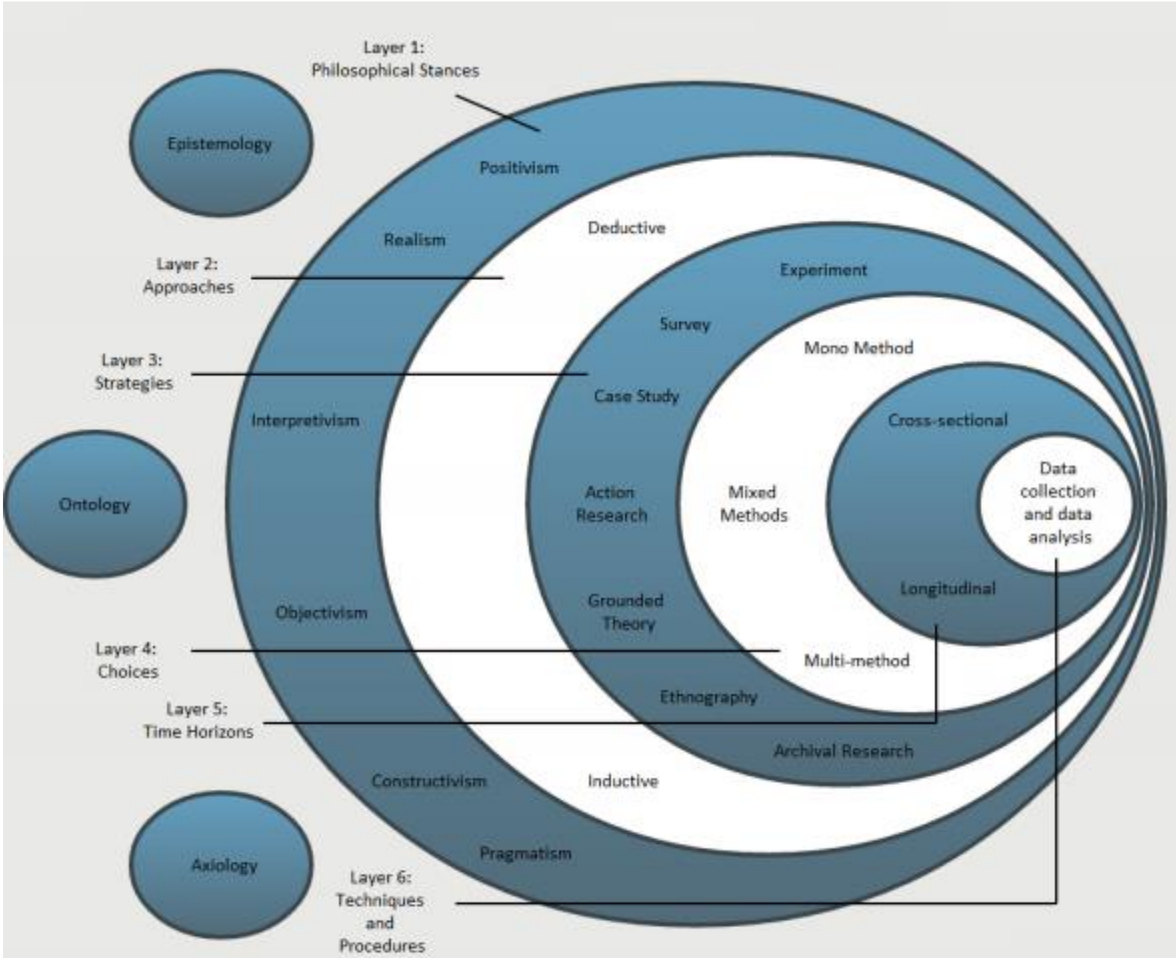

Figure 7.3. The Research Onion, based on the diagram given by Saunders et al (2009).

Accordingly, this technique constructs a six level hierarchy of research philosophies and approaches with the ultimate goal being that of data collection and data analysis. Figure 7.3 (UoD 2013) incorporates an additional layer, which is concerned with the philosophies of Epistemology, Ontology and Axiology.

7.2.2.1. Epistemology, Ontology and Axiology

Although these three approaches exist outside of the onion, the choice of philosophical approach taken will impact upon the subsequent direction the research study takes. These will need to be discussed in order to contextualise the research against the body of knowledge and research traditions already in existence.

Epistemology – is concerned with what constitutes acceptable knowledge in the field of study (Saunders 2009, 112). From a design-orientated versus behaviour-orientated research perspective, this means clarifying how reliable the available data is towards solving an issue, but also means appraising how relevant the data is towards the issue. This means looking for correlations between the products sold and the customers which bought them. Irrelevant data would be any data which does not inform this correlation.

Ontology – is concerned with the nature of reality. Within the context of academic research, however, ontology is concerned with three approaches: objectivism, constructivism and pragmatism (UoD 2013, 2).

Objectivism implies that social phenomena and their meanings exist independent of social actors (UoD 2013, 3). For example, we might consider whether a food retailer can exist independent of its customers. Yet whilst this reasoning may at first appear banal, it helps to illustrate why certain aspects of the business model are not functioning, i.e. food retail can only exist in the presence of customers. Hence, objective reasoning elucidates questions we would not otherwise be able to pose.

By comparison, constructivism argues that social phenomena are constructed by social actors (ibid.). Therefore, the premise “food retailers exist only as long as there are customers to buy food” is a constructivist statement.

Pragmatism allows the researcher to approach the problem from either an objectivist or a constructivist perspective. Therefore, a pragmatic question would be to ask whether there is sufficient reason to continue selling a specific food item (i.e. an objectivist approach) but to inform that reasoning based on specific customer behaviour patterns (i.e. a constructivist approach).

Axiology – is concerned with judgements about value (Saunders 2009, 116; UoD 2013, 2). It allows the researcher to understand the role their values or opinion plays in the collection and analysis of research rather than seeking to eliminate it. For example, an axiological question would be whether an increased level of customer pull leads to more sales being made by the retailer. If this premise turned out to be negative we would have to accept that customer-driven demand was secondary to manufacturer-driven demand for whatever reason.

We then come to the six layers of the onion. Each of these will be discussed below.

7.2.2.2. Level One – Positivism, Realism, Interpretivism and Pragmatism

Positivism – is the generation of hypotheses which can be independently verified based on measures of accepted knowledge (UoD 2013, 4). It implies that, as with the natural world, all systems of interaction have knowable, verifiable and repeatable rules. In relation to the

CFSC, this infers that customer behaviour patterns can also be modelled based upon a set of accepted criteria.

Realism – There are two levels involved with realist study: direct realism and critical realism (Saunders 2009, 115). Direct realism is concerned with the direct observation of phenomena, whilst critical realism is the acceptance of multiple levels within the system under observation. This implies that conclusions can only be drawn concerning customer purchasing habits based upon observable trends. This also means that the likelihood of specific products being sold regularly (i.e. milk, bread, fresh vegetables, etc.) is likely to increase once the purchasing patterns of regular customers are known.

Interpretivism – (or anti-positivism) suggests that there is a fundamental difference between the natural world and how people behave socially (Saunders 2009, 116). It suggests that the initial premises behind our concepts, ideas and language may be unreliable or only partially formed. This implies that many of the assumptions about customer purchasing habits may be inaccurate because the data had been compiled inaccurately or inappropriately, and had ignored important criteria concerning customer purchasing habits.

Pragmatism – although previously discussed in relation to ontology, here pragmatism implies that a combination of positivism, realism and interpretivism should be used in order to obtain a balanced profile of research. Therefore, we can determine that:

1. Customer behaviour patterns can be modelled based upon a set of accepted criteria;
2. The likelihood of specific products being sold regularly is likely to increase once the purchasing patterns of regular customers are known;

3. Assumptions about customer behaviour patterns may be subject to change due to important criteria, e.g. customers may purchase more of certain products at Christmas than at other times, customers may purchase from a rival retailer leading to a decline in sales, or customers may cease buying a product (i.e. beef burgers or eggs) due to a public health scare.

7.2.2.3. Layer Two – Deductive and Inductive

Deductive – this is when the research is designed to test a hypothesis, typically by asking a question based on a theory. For example, testing whether a pull system produces more food sales than a push system would be a deductive methodology which tested the effectiveness of a Lean implementation.

Inductive – this is where the researcher constructs a theory based around a research question after detailed observation, description and analysis. In this case, upon observing that there was a correlation between the kinds of food items being sold by a retailer and the frequency with which those items are purchased by the customers, we would induce that sales would increase if the retailer provided a closer match to the items which the customer wanted to buy.

7.2.2.4. Layer Three – Experiment, Survey, Case Study, Action Research, Grounded Theory, Ethnography, Archival Research

Experiments are rigid, scientific tests which enable the result to be reproduced independently by another researcher. The experiment is typically compared against a control group or null hypothesis, such that the causal effects of the observable phenomena can be verified.

Surveys are a structured way of obtaining specific information pertaining to the "who, what, where, why, when or how" of a specific topic or issue, typically via deductive questions.

Case studies involve extensive examination of one or more cases in a real life context. However, conclusions drawn are generally limited to a specific case study example. Hence, we must be aware of the limitations within that study. In addition, the researcher must present an accurate account of the conditions under which the study was performed as well as the reasons why it was performed.

Action research is concerned with addressing issues to find and implement solutions. It consists of a clear diagnosis of the problem and a generated list of possible solutions (or actions) to resolve that problem. This could be reasons why certain products sell more than others, or it could be a way of encouraging more customers to buy from the retailer.

Grounded theory uses inductive methods to predict and explain behaviour in order to build a theory. This implies that many partial or incomplete hypotheses can be combined in order to implement an improved theory.

Ethnography is the study of others from a detached perspective. This could mean that certain kinds of food are predominantly consumed by particular social or ethnic groups

Archival research is based on data collection from existing data sets or archive documents. This implies that company data relating to specific products and customer sales can be compared against archived records in order to illustrate an improvement or a decline which would not otherwise be observable.

7.2.2.5. Layer Four – Mono-method, Mixed-method, Multi-method

At this level of the onion, research can be either qualitative-based, quantitative-based or some combination of the two. Qualitative research is primarily exploratory research. It is concerned with the "why and how" of research, rather than the "who, what, where or when" of research. Quantitative research by comparison is more specific. It is used to quantify the research by generating numerical data or data which can be transformed into useful statistics. A comparison of the strengths and weaknesses of each approach is shown in table 7.1. below:

Quantitative	Qualitative
Strengths Wide coverage Fast and economical Hypothesis and theory testing Considerable relevance to policy decisions	**Strengths** To examine change processes over time Understand people's meanings Adjusts to new issues and ideas as they emerge Theory and hypothesis development
Weaknesses Inflexible, artificial and reductionist Not effective in explaining process Not effective in explaining the significance people attach to actions Not good at generating theories Does not offer policy-makers solutions	**Weaknesses** Time and resource consuming Analysis and interpretation of data is subjective Hard to control pace, progress and end-point Low credibility by policymakers

Table 7.1. A comparison between quantitative and qualitative methods (Adapted from: Easterby-Smith et al 1991)

A mixed-method therefore incorporates both qualitative and quantitative analysis, whilst a multi-method is one where the researcher uses both qualitative and quantitative analysis but the researcher's outlook is biased towards only one of them. Because food consumption is dependent upon people's behaviour patterns, a mixed or multi-method approach is the most appropriate, but with a bias towards quantitative data analysis wherever this is possible (i.e. controlled experimental data analysis, structured questionnaires, etc.).

7.2.2.6. Layer Five – Cross-sectional or Longitudinal

Cross-sectional research can use qualitative and quantitative analysis and they are used to measure an aspect or behaviour of many groups or individuals at a particular point in time.

Longitudinal research can also use qualitative and quantitative analysis but they are used to assess an aspect or behaviour of many groups or individuals but over a longer period of time.

It follows that longitudinal research is the most appropriate, since the study is concerned with ways of improving the performance of companies within the chilled food supply chain.

7.2.2.7. Layer Six – Data collection and analysis

This is the final level of the onion and signifies the best overall strategy for the researcher to adopt, given that the previous five levels have been worked through. It includes decisions on sample groups, questionnaire content, and questions to be asked during interviews and so forth. However, this stage should also be consistent with the reasoning which has been followed throughout the first five layers.

7.2.3. Summary of Research Approach

In summary, the research should:

1. Adopt a combined epistemological, ontological and axiological approach.
2. Adopt a pragmatic approach to the research, i.e. a combination of positivism, realism and interpretivism should be used in order to obtain a balanced profile of research.
3. Incorporate deductive questions based on provable theory and interpret the data based on inductive reasoning.
4. Use a combination of structured experimental tests and targeted survey questions where relevant (in terms of compiling a list of models and algorithms currently in operation).
5. Use the results of case study data to inform the direction of the research survey (i.e. which models and algorithms currently in operation are the leading approaches).
6. Use a combination of action research, grounded theory, ethnography (where relevant) and archival data
7. Adopt a mixed or multi-method approach, but with a bias towards quantitative data analysis wherever this is possible.
8. Adopt longitudinal research, since the study is concerned with ways of improving the performance of companies within the chilled food supply chain.

7.3. Hypotheses

From the four research questions and the literature search, the following key issues were identified:

1. The CFSC derives from other supply chain networks, which means that it inherits problems which are not easy to resolve or which presently have no complete solution.
2. Most of these problems are related to demand variation, including variation in rates of perishability, variation in size and quality of items (e.g. fruit, vegetable or eggs).
3. In turn, demand variation introduces uncertainty into which items should be MTO and which should be MTS.
4. There is also uncertainty within the CFSC concerning food quality, safety and traceability, because these factors have not been monitored closely enough.
5. However, the monitoring issue itself arises from the inherent weaknesses of the SCOR model. In particular, the Strategic, Tactical and Operation levels become increasingly ambiguous given the increased complexity of the CFSC.
6. As a consequence of the SCOR model's inadequacies, it may not be immediately obvious what priority should be attached to which performance measures.

Hence, we can now outline the hypotheses upon which the remainder of this study will be based.

Hypothesis One

It is feasible to implement the "bounded rational" DEA model as a benchmarking tool for each of the key issues identified. Hence, we are looking to express each of the key issues identified as affecting the CFSC in terms of a DEA model.

Hypothesis Two

It is feasible to construct an alternative to the SCOR model, based on four decision matrices, Managerial, Logistical, Relationships and Innovation, but which incorporates AHP or uncertain AHP to determine the relative hierarchy of the key performance factors (i.e. a "league table", which compares the company's KPFs with those of its competitors), and which uses "bounded rational" or uncertain DEA to establish realistic thresholds in order to assess the performance of each performance factor. In addition, the new model needs to satisfy the following conditions:

1. It should adopt a supply chain wide approach;
2. It should incorporate a network-orientated logistics-controlling mechanism;
3. It should address sales and marketing, product development, research and development and some elements of post-delivery customer support;
4. It should consider multiple perspectives of the problem owners and allow for the time phasing of objectives.

7.3. Conclusions

This chapter has outlined the methodology that will be used for this study. It has also identified two hypotheses upon which the proposed "bounded rational" hybrid AHP-DEA solution will be based.

Chapter Eight – Applying AHP, DEA or a Hybrid AHP-DEA Model to the CFSC

8.1. Introduction

From Hypothesis One, as given in the Methodology, it is proposed that a "bounded rational" hybrid AHP-DEA model would be the most effective approach towards resolving the key issues and the inherent uncertainty identified within the CFSC. This means that many of the existing models can be readily adapted to "bounded rational" models by establishing "upper" and "lower" bounds, based on the belief degree of data available (since we anticipate that this data will be limited). Hence, this phase of the study is concerned with compiling and/or developing existing models for each of the issues identified into a form that can be expressed as a DEA model, or which already exist as hybrid AHP-DEA models. Accordingly, the following issues will be tackled:

1. Existing AHP-DEA hybrid models;
2. The key issues identified within the CFSC;
3. Deciding the decoupling point within a hybrid MTO-MTS model;
4. How to measure and improve the performance of the existing supply chain model;
    a. How to determine the weightings of key performance factors within the CFSC;
    b. How key performance factors might be audited.

Hence, the structure of this chapter is given in Figure 8.1 below:

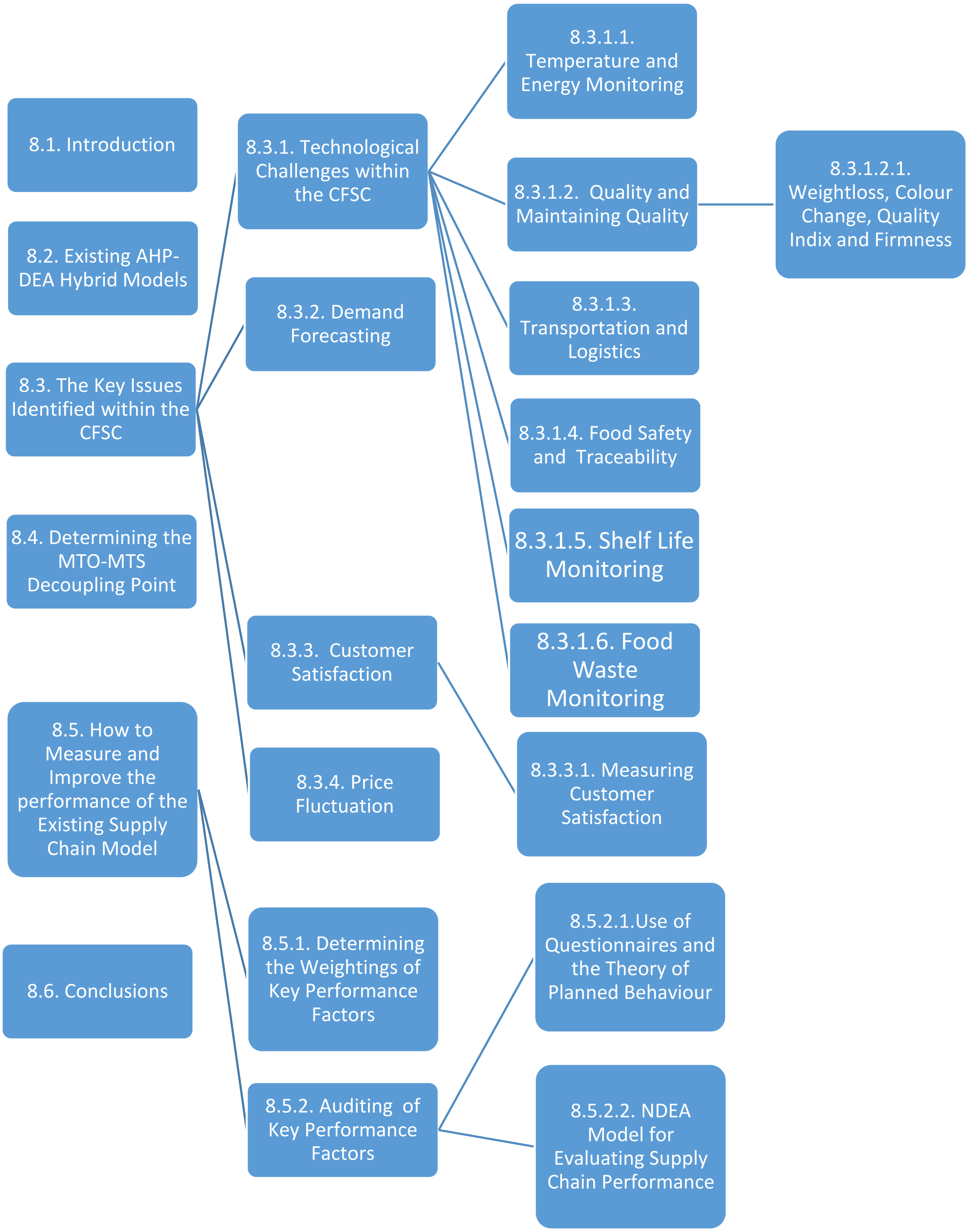

Figure 8.1. to illustrate the structure of Chapter Seven

8.2. Existing AHP-DEA Hybrid Models

The following studies have successfully combined AHP and DEA into a hybrid model.

Bowen (1990) compared the AHP and DEA methods for a site selection problem and discussed their similarities in both structure and results.

Shang and Sueyoshi (1995) used an accounting procedure to determine the DMU inputs, whilst DMU outputs were determined via an AHP model to examine nonmonetary criteria associated with corporate goals and long-term objectives, and used the simulation model to analyse the tangible benefits.

Seifert and Zhu (1998) investigated excesses and deficits in Chinese industrial productivity by combining the DEA with other management science approaches such as Delphi, AHP and assurance region (AR) techniques.

Zhang and Cui (1999) developed a project evaluation system for the State Information Center of China to manage investments in the various parts (sub-systems) of the State Economic Information System (SEIS) of China.

Sinuany-Stern, Mehrez, and Hadad (2000) presented an AHP/DEA methodology for fully ranking organizational units with multiple inputs and multiple outputs.

Yang and kuo (2003) used AHP and DEA to solve a layout design problem.

Takamura and Tone (2003) conducted a comparative site evaluation study for relocating Japanese government agencies out of Tokyo, putting emphasis on the methodological aspects.

Saen et al (2005) proposed a method of determining relative efficiency of slightly nonhomogeneous decision making units (DMUs) by using the DEA.

Liu and Hai (2005) presented a voting AHP method for supplier selection.

Ramanathan (2006) proposed a DEAHP method, which uses the DEA to generate local weights of alternatives from pairwise comparison matrices used in the AHP and to aggregate the local weights of alternatives in terms of different criteria into final weights.

Ertay et al (2006) suggested decision-making methodology based on the DEA and AHP for evaluating facility layout design (FLD).

Guo et al (2006) used a combined DEA/AHP model for evaluating supply chain performance.

Wang et al (2008) used AHP to determine the weights of criteria, linguistic terms such as High, Medium, Low and None to assess bridge risks under each criterion, the data envelopment analysis (DEA) method to determine the values of the linguistic terms, and the simple additive weighting (SAW) method to aggregate bridge risks under different criteria into an overall risk score for each bridge structure.

Giokas and Pentzaropoulos (2008) presented a hybrid AHP-DEA model for use in telecommunication efficiency rating.

Azadeh et al (2008) integrated DEA and AHP simulation model can be used for selecting optimum alternatives by considering multiple quantitative and qualitative inputs and outputs.

Sueyoshi et al (2009) presented a combined DEA and AHP model for conducting an internal audit prioritisation in a rental car company.

Yu and Lee (2013) used a combined AHP/DEA-AR and AHP rating method considering technology alternative’s required levels of input resource for optimal promising emerging technology selection.

8.3. The Key Issues Identified within the CFSC

From Chapter Two the following key issues have been identified within the CFSC:

7. Technological challenges within the CFSC;
    a. Temperature and energy monitoring;
    b. Quality and maintaining quality;
    c. Transportation and logistics;
    d. Food safety and traceability;
    e. Shelf life monitoring;
    f. Food waste monitoring;
8. Demand forecasting;
9. Customer satisfaction;
10. Price fluctuation.

Models for each of these issues will be given below.

8.3.1. Technological Challenges within the CFSC

As discussed in Chapter Two we need to consider the following six factors:

1. Temperature and energy monitoring;
2. Quality and maintaining quality;
3. Transportation and logistics;
4. Food Safety and Traceability;
5. Shelf life monitoring;

6. Food waste monitoring.

Models for each of these issues will be given below.

8.3.1.1. Temperature and Energy Monitoring

From Yang and Quo (2003), the shorter the path between input and output stages of the supply chain the shorter the time taken and hence the less energy is used. Hence, the data collection stage should include anticipating all of the temperature and energy requirements involved in moving the products from point A to point B within the supply chain network. Yet this task involves qualitative as well as quantitative analysis, rather than just the quantitative analysis of temperature and energy requirements alone. Hence, a hybrid AHP-DEA approach is required.

Azadeh et al (2008) examine ways of reducing the average traverse time of passenger and cargo trains by taking into account the qualitative as well as quantitative criteria affecting this. Therefore, a reduction in traverse time also signifies a reduction in overall temperature and energy costs. With this revision to the reasoning of Azadeh et el (2008) the following considerations are then considered:

1. Overall scheduled traverse time;
2. Unscheduled stoppage time;
3. Operator errors;
4. Installation of new equipment.

However, unscheduled stoppage time, operator errors and the installation of new equipment are qualitative factors, given that their duration and occurrence across the CFSC is uncertain. Hence, the underlying criterion for reducing the total traverse time is the reliability of the schedule used.

Once the criteria which define total traverse time have been identified, their weightings are calculated using AHP.

Zanoni and Zavanella (2012) consider each level of the supply chain in terms of energy efforts (Zanoni and Zavanella 2012, 733). Hence, this reframes the problem into that of the ratio of the different coefficients of performance of the cooling process (COP). It is then possible to calculate the energy required to chill and/or maintain products to a fixed temperature. Given that the optimum number of points along the CFSC can be determined by calculating the total traverse time allowed for moving chilled products from point A to point B it follows that COP can be re-expressed as a summation:

$$COP_{total} = \sum_{i=1}^{n} COP_i \qquad \text{(Equation 8.1)}$$

Zanoni and Zavanella (2012) also consider the total cost to the producer (TC_p), which is a function of batch size (Q) and the cooling and treatment process (T_p). This can be expressed in terms of the specific energy consumption (SEC) required to cool a kilogram of food to a given temperature level (given in units of kWh/kg), the cost of cooling energy (ec given in units of £/KWh), the demand (d), the set up cost at the production facility (K_p) and the ratio (ρ_{T_p}) between the COP set at the cooling temperature by the producer (COP_p) and the COP set at the reference or ambient temperature (COP_r). This expression is given as follows:

$$TC_p(Q, T_p) = \left(SEC \times ec \times d + K_p \frac{d}{Q}\right) \rho_{T_p} \qquad \text{(Equation 8.2)}$$

8.3.1.2. Quality and Maintaining Quality

Quality of food products decreases over time, as given by the following function:

$$\frac{dq}{dt} = -kq^n \qquad \text{(Equation 8.3)}$$

Here q is a measure of quality, k the rate of degradation and n is the order of reaction which determines how much quality is left within a specific product. However, quality degradation is connected to temperature via the Arrhenius equation:

$$k = k_0 e^{-(E_a/RT)} \qquad \text{(Equation 8.4)}$$

where k_0 is a constant, $E_a$is the activation energy, R is the gas constant and T is the absolute temperature. Nakandala et al (2016) use these equations to provide expressions for $q(t)$ such that quality degradation becomes a function of time. Accordingly, for a zero-order reaction food types (i.e. $n = 0$) we have:

$$q(t) = -k \times t + q_0 \qquad \text{(Equation 8.5)}$$

For first-order reaction food types (i.e. $n = 1$) we have:

$$q(t) = e^{-k \times t + \ln(q_0)} = e^{-k \times t} + e^{\ln(q_0)}$$

$$= q_0 e^{-k \times t} \qquad \text{(Equation 8.6)}$$

However, Nakandala et al (2016) also present an equation for quality degradation based on the total transit (or traverse) time, $\frac{d_{i,i+1}}{\vartheta_{i,i+1}}$, and the rate of deterioration as a function of storage temperature, $k_j(T_{i,i+1})$, where $d_{i,i+1}$ is the distance between point A and point B in the CFSC and $\vartheta_{i,i+1}$ is the speed of travel between point A and point B in the CFSC. Accordingly, this expression is given as:

$$q_j = q_{j0} - \sum_{i=1}^{N} P_{ji} \times \frac{d_{i,i+1}}{\vartheta_{i,i+1}} \times k_j(T_{i,i+1}) \qquad \text{(Equation 8.7)}$$

Here P_{ji} is a binary indicator of whether product j is on the truck at stop i which is equivalent to saying whether or not a product is in the inventory between point A and point B. However, Nakandala et al (2016) note that in practice the storage temperature and the storage period are provided (Nakandala et al 2016, 571). Hence $\frac{d_{i,i+1}}{\vartheta_{i,i+1}}$ can be substituted for t_{store} which then provides a measure of uncertainty (i.e. t_{store} will consist of both scheduled and unscheduled time periods), such that:

$$t_{store} = \sum_{i=1}^{n} t_{i,i+1} \qquad \text{(Equation 8.8)}$$

Hence, if we are only concerned with items that are in the inventory, we can rewrite the above equation as:

$$q_j = q_{j0} - \sum_{i=1}^{n} t_{i,i+1} \times k_j(T_{i,i+1}) \qquad \text{(Equation 8.9)}$$

Hence, the expression for q_j reduces to a DEA model.

8.3.1.2.1. Weight Loss, Colour Change, Quality Index and Firmness

Cortbaoui and Ngadi (2015) apply Taguchi's loss functions to measure the quality loss of cucumbers after harvest. Accordingly, variations in weight loss and colour change are described as "smaller the better" changes, since colour and moisture retention are more desirable attributes to the customer. This is given by the equation:

$$L = k_L(y)^2 \qquad \text{(Equation 8.10)}$$

where k_L is the proportionality constant and y is the studied quality attribute. However, firmness and quality index are described as "larger the better", given that the customer demands firmer, higher quality cucumbers. This is given by the equation:

$$L = k_L\left(\frac{1}{y}\right)^2 \qquad \text{(Equation 8.11)}$$

Based on a range of 1 to 100, values are plotted against $\left(\frac{1}{y}\right)^2$ and $(y)^2$ separately and the value of k_L determined. Hence, L can be determined.

A percent influence factor P_i is also considered necessary in order to determine by how much each environmental factor impacts upon the quality attributes of cucumbers. This is calculated using the following formula:

$$P_i = S_f - \frac{(V_e \times f_F)}{S_T} \times 100 \qquad \text{(Equation 8.12)}$$

where S_f is the sum of squares of a particular factor, V_e is the variance for the error term and f_F is the degree of freedom of a particular factor and S_T is the total sum of squares of all factors.

Total colour loss ΔE is given by

$$\Delta E = \sqrt{\Delta L^2 + aL^2 + bL^2} \qquad \text{(Equation 8.13)}$$

where L^* defines the lightness of the product, a^* describes the red/green coordinate, and b^* descries the yellow/blue value. Also, $\Delta L = L^* - L_0^*$, $\Delta a = a^* - a_0^*$, and $\Delta b = b^* - b_0^*$. Triplicate readings are taken in order to obtain a fairer representation of colour variation.

Weight loss WL is calculated as:

$$WL = 100 \times (W_i - W_f) \qquad \text{(Equation 8.14)}$$

where W_i is the initial weight and W_f is the final weight.

Firmness, or texture, is evaluated using a compression test and an average or three readings is taken.

Each predicted quality attribute (i.e. “Firmness”, “Quality Index”, “Total Colour Index” and “Weight Loss”) is then determined by establishing three levels of variation for temperature, time, humidity and light.

8.3.1.3. Transportation and Logistics

As mentioned in Chapter Two, the most studied transportation problem in this area is the capacitated vehicle routing problem (CVRP). The problem is well articulated by Laporte (1992). However, Akhand et al (2016) put the problem into the following terms, which are much closer to our needs:

$$Minimise \sum_{i\in N} \sum_{j\in N} \sum_{V\in N} C_{ij} X_{ij} \qquad \text{(Equation 8.15)}$$

$$subject\ to$$

$$\sum_{v\in V} y_i = 1 \quad for\ i \in N \qquad \text{(Equation 8.16)}$$

$$\sum_{i\in N} x_{ij} = y_j \quad for\ j \in N\ \ and\ v \in V \qquad \text{(Equation 8.17)}$$

$$\sum_{j\in N} x_{ij} = y_i \quad for\ i \in N\ \ and\ v \in V \qquad \text{(Equation 8.18)}$$

$$\sum_{i\in N} d_i y_i \le Q\ \ for\ v \in V \qquad \text{(Equation 8.19)}$$

$$\sum_{i \in N} x_{i1} \le 1 \quad for\ \ v \in V \qquad \text{(Equation 8.20)}$$

$$\sum_{j \in N} x_{1j} \le 1 \quad for\ \ v \in V \qquad \text{(Equation 8.21)}$$

Accordingly,

1. Equation 8.15 signifies the total travel distance, C_{ij}, that is to be minimised,
2. Equation 8.16 signifies the constraint that each customer must be visited once by one vehicle, where $y_i = 1$ if vehicle v visits customer i, but is zero otherwise;
3. Equation 8.17 and equation 8.18 signify that each customer is visited and left with the same vehicle, where $x_{ij} = 1$ if vehicle v travels from customer i to customer j but is 0 otherwise;
4. Equation 8.19 ensures that the total delivery demands of vehicle v do not exceed the vehicle capacity;
5. Equation 8.20 and equation 8.21 signify that the vehicle availability should not be exceeded.

8.3.1.4. Food Safety and Traceability

As noted in section 2.2.1.5., there are two kinds of traceability: "chain traceability" and "internal traceability". However, traceability itself is further sub-divided into "tracing" (i.e. finding the source of quality control issues) and "tracking" (i.e. the localisation of products from one or more criteria in every point of the supply chain to aid with product recall issues). Food safety is therefore concerned with ensuring that food traceability models are sufficiently robust. That is, effective information generated by food traceability systems can aid with contractual arrangements between companies across the CFSC in order to promote food safety (Resende-Filho and Hurley 2012, 596).

Dabbene et al (2013) list the following factors as being the main reasons for food product recalls:

1. Failure to endorse good manufacturing practice;
2. Incorrect packaging and labelling;
3. Identification of conditions that can compromise the safety of the food and the consumer's health, e.g. microbial agents, chemical contamination, foreign material, undercooking of product, etc.
4. Undeclared contamination of raw and semi-processed materials with allergens, e.g. eggs, peanuts, diary and wheat.

It follows that all of these issues could have been avoided through good tracing protocols being in place.

Resende-Filho and Buhr (2010) provide the following equation for the cost of product recall:

$$RC = \alpha P_r Q_r \qquad \text{(Equation 8.22)}$$

where RC is the recall cost, α is a coefficient accounting for notification, logistics, etc. P_r is the retail value and Q_r is product quantity to be recalled. Dabbene et al (2013) compare this model with the Fritz and Schieffer (2009) equation for the overall cost of a traceability system:

$$C(overall) = RC + C(tt) + C(e) + C(q) \qquad \text{(Equation 8.23)}$$

where $C(overall)$ is the overall cost, $C(tt)$ is the cost of the system, $C(e)$ is the cost of reduced efficiency and $C(q)$ is the cost of reduced quality.

By contrast, Dupuy et al (2005) propose solution to the traceability problem, which perceives traceability as a graphical dispersion problem. Accordingly, each node represents a batch and each edge represents a link between two batches, if one batch contains material coming from the other batch. The problem is then divided into three levels: raw materials, components (i.e. manufactured components and bought-in components) and finished products.

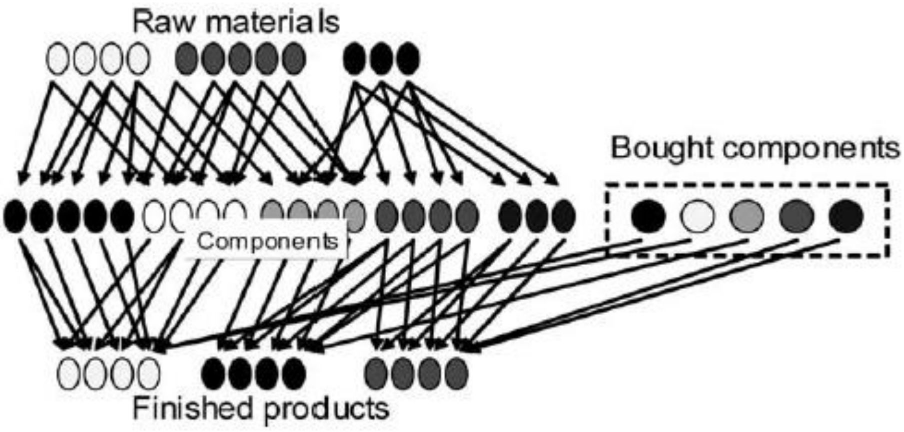

Figure 8.2. Diagram of the graphical dispersion problem as given by Dupuy et al (2005).

The Dupuy et al (2005) model is then concerned with optimising the batch dispersion cost (BDC) of a traceability system. The BDC is made up from the total downward and upward dispersion indices of all raw materials as given by:

$$Minimise \sum_{i=1}^{M} \sum_{k=1}^{P} Y(i,k) + \sum_{l=1}^{M} \sum_{k=1}^{P} x_{BF}(l,k) \qquad \text{(Equation 8.24)}$$

Where M is the number of raw material batches, P is the number of finished product batches, $Y(i,k)$ is the sum of links between raw material batches and finished product batches, and $x_{BF}(l,k)$ is the dispersion due to bought components.

However, whilst it follows that the performance of an effective traceability system is based upon the total number of active paths between raw materials and finished products, we can consider the efficiency of the Dupuy et al (2005) model in terms of Sueyoshi et al (2008)'s combined DEA-AHP auditing model.

Accordingly, the DEA efficiency of the kth term is given by

$$min\left\{\theta|\theta X_k - \sum_{j=1}^{n}\lambda_j X_j \geq 0, \sum_{j=1}^{n}\lambda_j Y_j \geq Y_k; \theta : URS\ and\ \lambda_j\ \geq 0\ \ for\ j = 1,..,n\right\}$$

(Equation 8.25)

where λ is a column vector of "intensity factors" for connecting inputs with outputs. The efficiency score θ is unrestricted (URS). If θ is unity then the kth term DMU is considered to be efficient. If θ is less than unity then the kth term DMU is considered to be inefficient. This model is converted to the constant returns to scale (CRS) model by the addition of the constraint

$$\sum_{j=1}^{n}\lambda_j = 1 \qquad \text{(Equation 8.26)}$$

Hence, we have

$$\min\left\{\theta|\theta X_k - \sum_{j=1}^{n}\lambda_j X_j \geq 0, \sum_{j=1}^{n}\lambda_j Y_j \geq Y_k, \sum_{j=1}^{n}\lambda_j = 1; \theta : \text{URS and } \lambda_j\ \geq 0\ \ \text{for } j = 1,..,n\right\}$$

(Equation 8.27)

This model is also known as the BCC model after Banker et al (1984). It ensures convexity for a given set of data. However, the auditing process is only concerned with DMUs that are inefficient.

The audit process is based on a risk experience level in which each of the criteria are assigned a risk factor. When the overall risk level dips below a threshold, an audit is taken and the underperforming aspect of the business is identified.

AHP is used to process the qualitative information as given by past audits, management's experiences and judgements, whilst the above BCC DEA model is used to measure quantitative data. This approach has the advantage of giving a measure of the risk or urgency and the efficiency of the model.

However, the data set used in the Sueyoshi et al (2009) study has mixed ratios with continuous data. There may be a methodological difficulty regarding the reliability of DEA scores and target values. This study considers all variables as continuous, i.e. days per annum. This study also assumes that multiple solutions and multiple projections do not occur in the proposed DEA application.

In addition, Resende-Filho and Hurley (2012) present a model for traceability of raw materials within the CFSC based on a three-level reward or penalty incentive. This model makes the following assumptions about food safety:

1. Based on the probability $1 \geq F \geq 0$ that a firm upstream of the source problem is defect free, $F = F(a)$ with $F'(a) > 0$ and $F''(a) < 0$, where a is the firm's effort to reduce to reduce food safety risk (Equation 8.28).
2. If $I_m$is the contingency payment made to an agent based on the level of defects leading to an increase in food safety, $I_1 > I_2$ (Equation 8.29). Accordingly, an agent is rewarded if it can be shown that an agent provided material free from defect (this is known as payment I_0). Where it can be shown that an agent provided material that was defective, the agent is penalised (this is known as payment I_1). A third payment is made when it cannot be proven whether an agent has provided defective material (this is known as payment I_2). Hence, there is an incentive for the agent to provide defect free material to a firm.

3. If $u(I_m)$ is the Bernoulli utility function and $c(a)$ is the cost of effort function, $u'(I_m) > 0$, $c'(a) > 0$ and $c''(a) > 0$ $(\text{Equation } 8.30)$. In other words, the effective utility increases with a decrease in the number of defects. However, from an incentive perspective, an agent needs to be aware that the more defects within the supply chain leading to safety risk, the greater that risk to public health (e.g. the BSE crisis).
4. $u(\cdot) \leq 0$, that is, agents are either risk neutral (i.e. $u(\cdot) = 0$) or risk averse (i.e. $u(\cdot) < 0$) $(\text{Equation } 8.31)$. By contrast, an agent is said to be risk loving if (i.e. $u(\cdot) > 0$).
5. If $g(\cdot)$ is the cost of traceability as a function of precision and s is the level of precision required, $g'(s) > 0$ and $g''(s) > 0$ for $1 \geq s \geq \underline{s}$, where $\underline{s}$ is a strictly positive minimum level of traceability automatically created when a traceability system is implemented $(\text{Equation } 8.32)$.

Hence, a combination of these five models would allow for a robust traceability system to be implemented, i.e.

1. The Resende-Filho and Buhr (2010) equation for the cost of product recall;
2. The Fritz and Schieffer (2009) equation for the overall cost of a traceability system;
3. Dupuy et al (2005) batch dispersion cost BDC objective function, which optimises the links between raw materials, components and finished products;
4. The Sueyoshi et al (2008) combined DEA-AHP auditing model would provide a measure of overall efficiency rating with regard to defects leading to food safety issues;
5. The Resende-Filho and Hurley (2012) assumptions for traceability of raw materials within the CFSC based on a three-level reward or penalty incentive.

Hence, we have already discussed these models and approaches.

8.3.1.5. Shelf Life Monitoring

According to Kilcast and Subrameniam (2000) shelf life is divided into intrinsic, extrinsic and implicit factors (Kilcast and Subrameniam 2000, 3, 57). Intrinsic factors are the properties of the final product. These include:

1. Water activity or available water, a_w;
2. pH value and total acidity (including type of acid);
3. Redox potential E_h;
4. Available oxygen;
5. Nutrients;
6. Natural microflora and surviving microbiological counts;
7. Natural biochemistry of the product formulation (i.e. enzymes, chemical reactants);
8. Use of preservatives in product formulation (e.g. salt).

Extrinsic factors are factors that affect the final product as it moves through the food chain. These include:

1. Time-temperature profile during processing;
2. Temperature control during storage and distribution;
3. Relative humidity (RH) during processing, storage and distribution;
4. Exposure to light (UV and IR) during processing, storage and distribution;
5. Composition of atmosphere within packaging;
6. Subsequent heat treatment (i.e. reheating or cooking prior to consumption);
7. Consumer handling.

Implicit factors are down to the characteristics of the microorganism itself and how it behaves in the presence of combinations of intrinsic and extrinsic factors. Implicit factors either inhibit or stimulate the following factors, which limit shelf life:

1. Microbiological;
2. Chemical;
3. Physical;
4. Temperature related issues (ibid.).

Mizrahi (2000) consider the “no model” approach to food deterioration. It assumes that a valid kinetic model exists but does not require experiments to determine it. The following derivation is based on (Mizrahi 2000, 120, 121). If we assume that the kinetically active factor F is changing during storage in a monotonically and continuous way we know that it is changing as a function of time. Hence,

$$F = g(t) \qquad \text{(Equation 8.33)}$$

Hence, the inverse function will relate

$$t = f(F) \qquad \text{(Equation 8.34)}$$

If a valid kinetic function for deterioration exists

$$dD = K(F)dt \qquad \text{(Equation 8.35)}$$

However, given that

$$\frac{dt}{dF} = f'(F) \qquad \text{(Equation 8.36)}$$

$$dt = f'(F)dF \qquad \text{(Equation 8.37)}$$

Hence

$$dD = K(F)f'(F)dF \qquad \text{(Equation 8.38)}$$

If we then consider two samples of the same product, one at actual storage conditions and one at accelerated test conditions, the ratio between their deterioration rates is

$$\frac{(dD)_s}{(dD)_a} = \frac{[K(F)f'(F)dF]_s}{[K(F)f'(F)dF]_a} \quad \text{(Equation 8.39)}$$

Hence $(dD)_s$ can be expressed as a function of $(dD)_a$ such that

$$(dD)_s = \frac{[K(F)f'(F)dF]_s}{[K(F)f'(F)dF]_a}(dD)_a \quad \text{(Equation 8.40)}$$

We can then consider the effects of F under storage conditions and under accelerated test conditions, such that

$$F = F_0 + b_s t \quad \text{(Equation 8.41)}$$

$$F = F_0 + b_a t \quad \text{(Equation 8.42)}$$

Where b is a constant.

Using the inverse form of these equations, the ration of their derivative is

$$\frac{f_s'(F)}{f_a'(F)} = \frac{b_a}{b_s} \quad \text{(Equation 8.43)}$$

Therefore the ratio between extent of deterioration under storage conditions and under accelerated test conditions is given by

$$(D - D_0)_s = \frac{b_a}{b_s} \frac{\left[\int_{F_0}^{F} K(F)dF\right]_s}{\left[\int_{F_0}^{F} K(F)dF\right]_a}(D - D_0)_a \quad \text{(Equation 8.44)}$$

$$= \frac{b_a}{b_s}(D - D_0)_a \quad \text{(Equation 8.45)}$$

The application is extended to the general case, where the equations are divided into n sections, such that each may be approximated by a straight line with a slope. The basic equation is then given as

$$\left(\Delta D_j\right)_s = \frac{f_s'\left(F_j\right)dF}{f_a'\left(F_j\right)dF}\left(\Delta D_j\right)_a = \frac{\left(b_j\right)_a}{\left(b_j\right)_s}\left(\Delta D_j\right)_a \quad \text{(Equation 8.46)}$$

Hence, the extent of deterioration is given by

$$(D - D_0)_s = \sum_j^n (\Delta D_j)_s = \sum_j^n \frac{f_s'(F_j)}{f_a'(F_j)} (\Delta D_j)_a \qquad \text{(Equation 8.47)}$$

With this model in place, we can now consider the effective deterioration rates for different kinds of chilled food products. E.g. milk and dairy products, confectionary products, fruit and vegetables, fats and oils, sauces and dressings, ready meals and so forth. Yet given that each product has a different set of deterioration criteria which is unique to that product, each set of deterioration criteria can be plotted. Hence, if we reconsider the four criteria which limit shelf life – microbiological, chemical, physical, and temperature-related – the task is then a matter of identifying what the deterioration issues are for each product under each category, and making the relevant chart. In this way deterioration can be monitored more visibly, and compared with standard data (i.e. DEA analysis) which would inform where and why abnormalities are appearing.

8.3.1.6. Food waste monitoring

Food waste as a loss can be modelled using Debreu's "dead loss" function (Debreu 1951, Pastora et al 2009). Accordingly, the dead loss function signifies lost revenue. The basic minimising dead loss function is based on

$$Min_z p_z \cdot (z_0 - z) \qquad \text{(Equation 8.48)}$$

where z_0 is a vector representing actual resources, z is a vector representing the optimal allocations and p_z is the intrinsic price vector. Pastora (2012) modifies this equation with the additional constraint:

$$\begin{aligned} &Min_z p_z \cdot (z_0 - z) \\ &subject\ to \quad p_z \cdot z_0 = 1 \end{aligned} \qquad \text{(Equation 8.49)}$$

However, we notice the similarity between this model and the "no model" deterioration model of Mizrahi et al (2000). This implies that a DEA loss function can be found for food waste monitoring purposes. Pastora et al (2009) gives this as:

$$L(x_0, y_0; NC) = Min_{c,p,\alpha}\ \alpha - \left(\sum_{r=1}^{s} p_r y_{r0} - \sum_{i=1}^{m} c_i x_{i0}\right)$$

$$subject\ to\ \ (c, p, \alpha) \in SH(T), \qquad NC(c, p) \qquad \text{(Equation 8.50)}$$

where α is free, $(x_0, y_0) \in R_+^m \times R_+^S$ and NC (i.e. normalisation condition) is a set of constraints on the intrinsic price vector, $p_r \in p = (p_1, p_2, \dots, p_s)$, $c_i \in c = (c_1, c_2, \dots c_m)$, and $SH(T)$ is the supporting hyperplane of T.

However, in order for the loss function to be represented by a finite set of equalities or inequalities, Pastora et al (2009) changes the normalisation condition to a linear normalisation condition (i.e. LNC). Hence, the above equation is rewritten as:

$$L(x_0, y_0; LNC) = Min_{c,p,\alpha}\ -\sum_{r=1}^{s} p_r y_{r0} + \sum_{i=1}^{m} c_i x_{i0} + \alpha$$

$$subject\ to\ \sum_{r=1}^{s} p_r y_{rj} - \sum_{i=1}^{m} c_i x_{ij} - \alpha\ \le 0, \forall j$$

$$c \ge 0_m, p \ge 0_s, \qquad LNC(c, p) \qquad \text{(Equation 8.51)}$$

However, Pastora et al (2009) suggests that the linear normalising condition (i.e. LNC) is given by

$$\sum_{i=1}^{m} c_i x_{i0} = 1 \qquad \text{(Equation 8.52)}$$

We recognise this as the constant returns to scale model.

Hence, we can write:

$$1 - L(x_0, y_0; LNC) = \sum_{r=1}^{s} p_r^* y_{r0} - \alpha^* \qquad \text{(Equation 8.53)}$$

However, if the DMU is efficient

$$\sum_{r=1}^{s} p_r^* y_{r0} - \alpha^* = 1 \Leftrightarrow L(x_0, y_0; LNC) = 0 \qquad \text{(Equation 8.54)}$$

Pastora et al (2009) also states that the value of the loss can be determined by multiplying this equation by the actual cost, C_0, such that we obtain:

$$C_0(1 - \theta^*) = C_0 L(x_0, y_0; LNC) \qquad \text{(Equation 8.55)}$$

8.3.2. Demand forecasting

As discussed in section 2.2.4., demand forecasting or order management is concerned with comparing data about current orders with historical data in order to produce requirements for finished products (Shapiro 1999, 744).

However, the most important criterion for evaluating and selecting a forecasting model is accuracy, or "the ability of a model to reproduce the past" (Xu and Ouenniche 2012, 580). Accuracy itself consists of three dimensions (ibid.):

1. Goodness of fit – refers to how close the forecast is to the actual values of the data;
2. Biasedness – refers to whether the model tends to over or under estimate forecasts;
3. Correct sign – this refers to whether a forecast is consistent with the trend that demand for products is either increasing or decreasing.

Xu and Ouenniche (2012) use the super-efficiency DEA because the emphasis is upon maximising goodness of fit and minimising biasedness without decreasing the ability of predicting the correct sign. Hence it follows that the Xu and Ouenniche (2012) super-efficiency DEA forecasting model can be adapted into a tracking.

8.3.3. Customer Satisfaction

Lewis and Mazvancheryl (2011) present a DEA model for measuring the efficiency of the customer satisfaction process, based on the American Customer Satisfaction Index (ACSI) Model (Fornell 1996). The ACSI model has subsequently become one of the most widely used models for evaluating customer satisfaction. As seen in the diagram below, the ACSI model is based on customer expectations and customer perceptions about quality, such that both of these provide an indication of value to the customer.

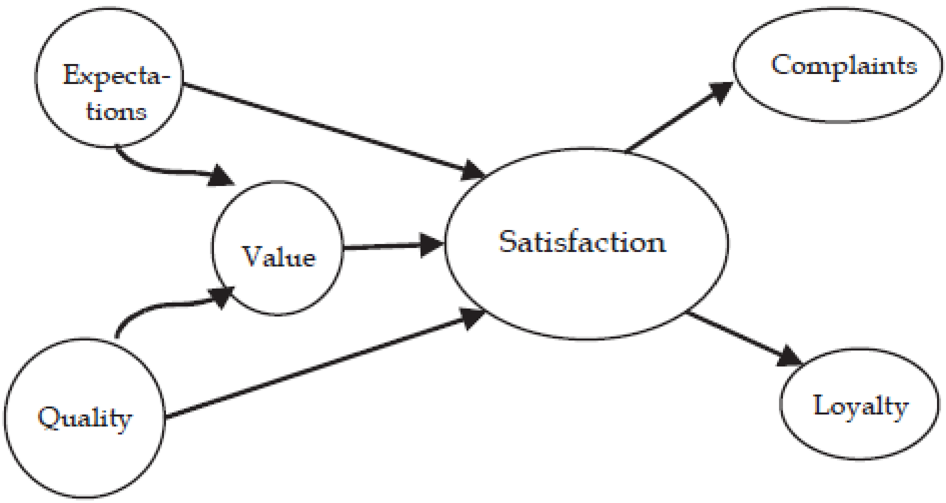

Figure 8.3. Diagram to illustrate the ACSI model of customer satisfaction based on Lewis and Mazvancheryl (2011).

Hence, the overall level of customer satisfaction will provide a measure of customer complaints and customer loyalty. Given that customer expectations are important in providing an overall measure of customer value, it can therefore be shown that the ACSI model embraces the three customer expectations of quality (i.e. basic factors, performance factors and excitement factors, as briefly discussed in Chapter Two) as given by Kano (1984).

8.3.3.1. Measuring Customer Satisfaction

Reiner (2005) discusses how financially orientated measures of business performance are becoming obsolete because their focus is too narrow and they fail to provide effective insight into the real drivers of business (i.e. customer demand). In his model process management and customer orientation are the main focus. He also states how:

> The cost of an offensive marketing strategy is usually higher than that of a defensive one. It is more expensive to attract a new customer than to keep an already existing one. The costs of an offensive business strategy are further increased on account of competitors adopting a successful defensive policy. Overall customer satisfaction is a function of customer requirements and customer satisfaction (Reiner 2005).

From cost terms this statement implies that the manufacturer-dominated supply chain is unnecessarily expensive. Customer retention is therefore key to understanding the success of a business (i.e. any business can only expand by increasing its number of customers).

The first step is to identify the firm's main business processes, and every process is characterised by performance measures that determine customer satisfaction. This allows customer demand to be quantified, but also measures overall customer satisfaction in terms of cost functions for every process in the business supply chain.

Reiner (2005) also states how a systematic evaluation of supply chain improvements should consist of three parts:

1. Supply chain performance measures (estimated by a discrete-event simulation model);

2. Customer satisfaction (estimated by systems dynamics model);
3. Financials (estimated by systems dynamics model).

Supply chain improvements then need to be evaluated under the following constraints:

1. Aggregated supply chain process performance measures (ASCPPM);
2. Generic supply chain process performance measures (GSCPPM).

8.3.4. Price Fluctuation

Olson and Wu (2011) present a seven-step DEA-based algorithm which acts as a "filter" in determining the most cost-effective supplier under uncertain conditions which affect price fluctuation.

However, from the material on the Cunningham equation given in Chapter Four, it follows that we can adapt this algorithm to give a more general representation of supplier performance under risk. For convenience the Cunningham equation is repeated here as:

$$Overall\_perceived\_risk = \sum_{i}^{n} uncertainty_i \times adverse\_consequences_i$$

(Equation 8.56)

Hence, the DEA inputs are given by the $\mathrm{Overall\_perceived\_risk}$ weightings. Hence, the DEA inputs derive from the factors identified by Mitchell (1998), which include: performance risk, physical risk, financial risk, psychosocial risk and time risk, but also; product-related factors, personal factors and situational factors. Clearly, these weightings will amount to much more than the currency exchange rate, product failure rate, relative frequency of product survival, organisational survival and political survival. In section 4.9., we considered the equivalence between "uncertainty" and "environmental demands", and between "adverse consequences" and "bounds on adaptability" by comparing Mitchell (1998) with

Jones (1999). Hence, price fluctuations are affected at three scales – global scale, country scale and local scale – by the key drivers for change. This also implies many of the risk factors may not be immediately visible at the local or country scale, but may suddenly impact upon business performance. It therefore follows that, even though the risks may be small, there is every need to factor these risks into the model.

8.4. Determining the MTO-MTS Decoupling Point

In section 3.5., we considered Rahimnia et al (2009)'s reasoning that the hybrid MTO-MTS problem can be divided into five strategies in terms of increasing strength of customer pull, ranging from BTO, MTO, ATO, MTS and STS. Hence, since the location of the MTO-MTS decoupling point is based on a 1 to 5 weighting in terms of strength of customer pull (i.e. with 1 corresponding to pure BTO and 5 corresponding to pure STS), we can adapt Sun et al (2008)'s algorithm to resolve this problem:

$$\min_{\vec{X}} \Pi = \sum_{i=1}^{nodes} \left(TC_i^{MTO} - TC_i^{MTS}\right) x_i$$

$$subject\ to$$

$$PT(\vec{X}) \leq DT, \qquad x_i \in \{0,1\} \qquad \text{(Equation 8.57)}$$

where TC_i^{MTO} is the total cost per element i for MTO, TC_i^{MTS} is the total cost per element i for MTS, PT is the production lead time and DT is the delivery time required by the customer.

8.5. How to measure and improve the performance of the existing supply chain model

This problem will be tackled in two stages:

1. How to determine the weightings of key performance factors within the CFSC;
2. How key performance factors might be audited in relation to the issues already identified within this chapter.

8.5.1. Determining the Weightings of Key Performance Factors within the CFSC

One of the main issues with key performance factors within the CFSC is that they are typically qualitative resources. This would imply that the weightings of the key performance should be determined via the AHP method. Joshi et al (2011) suggest that once weightings of the key performance factors have been determined using AHP the overall performance level of the company with respect to a predetermined threshold can be determined.

8.5.2. Auditing of Key performance Factors

From the earlier discussion of overall perceived risk in relation to the Cunningham equation, there may be many unprecedented events which impact upon key performance measures. For example, a crop failure or a food contamination crisis may alter prediction models. We might also consider that since key performance factors are often qualitative rather than quantitative the weightings used might be subjective.

Ren et al (2013) propose a model which aims to minimise total costs and reduce waste from unqualified items, while achieving necessary robustness in coping with generated risks. Here a level of compromise is established via a trade-off between cost, wastage and risks exposed. This is known as the level of compromise (Ren et al 2013, 938). Hence, we can assess key performance factors based upon the minimum dissatisfaction level.

8.5.2.1. Use of Questionnaires and the Theory of Planned Behaviour

In Chapter Four it was implied that “using uncertainty theory to model frequency may produce a crude result, while using probability theory to model belief degree may produce a big disaster” (Liu 2016, 8). It follows that the use of a questionnaire survey may not necessarily reflect the broader issues, i.e. the weightings may vary from company to company, or else variations may be felt differently at the local scale when compared with country-wide or global trends.

However, one of the leading methods used as the basis for questionnaire design is the theory of planned behaviour (Ajzen 2012, 438). The theory is based on two predictors: Attitudes Towards Behaviour, which measures the extent to which an individual has a favourable or unfavourable evaluation of the behaviour in question, and Subjective Norm, which measures the influence of other people in respect of the behaviour (Ajzen and Fishbein, 1980). These two predictors are contrasted against a set of what are believed to be Perceived Behavioural Control, which then provides a measure of Intention. However, an additional measure known as Actual Behaviour Control is used as a feedback mechanism. Behaviour is then perceived as a measure of Intention (i.e. Attitudes Towards Behaviour + Subjective Norm + Perceived Behavioural Control) which is regulated by Actual Behaviour Control.

However, this approach has been criticised (Sniehotta et al 2014, Sheeran 2013, Connor et al 2013) because it assumes a rational focus on behalf of the decision maker but excludes subconscious influences like the role of emotion beyond anticipated affective outcomes. In addition, Sniehotta (2009) demonstrated that whilst Behavioural Belief intervention resulted in post-intervention changes in attitudes, Intention or Behaviour was not affected. Sniehotta (2009) also demonstrated that Control Beliefs did not affect Perceived Behavioural Control, but that Control Beliefs affected Behaviour via direct objective monitoring.

Nevertheless, Ajzen (2006b, 4) states that an expectancy-value formulation can be determined by taking the belief strength b and the associated scale value of the belief as s. The aggregated set of beliefs is then given by

$$Aggregated_{Beliefs} = \sum b_i s_i \qquad \text{(Equation 8.58)}$$

Hence, we can begin with a crude measure of belief degree and improve upon it via the Ren et al (2013) method. Yet in comparison with adopting a questionnaire-based approach alone, the Ren et al (2013) method will take into account escalating costs, losses and wastage, as well as the risk factors given by the Cunningham equation. These additional factors will become available via open source data. Hence the Ren et al (2013) method reveals many hidden attributes which the decision maker might otherwise have been unaware.

8.5.2.2. NDEA Model for Evaluating Supply Chain Performance

Azbari et al (2014) propose a Network DEA model (NDEA) for evaluating supply chain performance, based on a variable returns to scale (VRS) rather than a constant returns to scale (CRS). Accordingly, the supply chain is perceived as a P-stage process, i.e. that the input stage will produce a vector of p outputs, where $p = 1, \dots, P$. Each of these outputs will take on two forms:

1. Outputs that are not passed on as the input to the subsequent stage z_p^1
2. Outputs that are passed on as the input to the subsequent stage z_p^2

In addition, there is provision for new inputs z_p^3 at the next $(p+1)$ stage. However, when $p = 2,3, \dots$, the following definitions are given:

1. z_{pr}^{j1} is the rth component $\left(r = 1, \dots, R_p\right)$ of the R_p-dimensional output vector for DMU_j flowing from stage p which leaves the process at that stage and is not passed on to stage $(p+1)$.
2. z_{pk}^{j2} is the kth component $\left(r = 1, \dots, S_p\right)$ of the S_p-dimensional output vector for DMU_j flowing from stage p which is passed on as a portion of the inputs to stage $(p+1)$.
3. z_{pi}^{j3} is the ith component $\left(i = 1, \dots, I_p\right)$ of the I_p-dimensional input vector for DMU_j at stage $(p+1)$ which enters the process at the beginning of that stage.

In the last stage P all outputs are viewed as z_{pr}^{j1} as they leave the process. The weightings for the above factors are defined as follows:

1. u_{pr} is the multiplier for the output components z_{pr}^{j1} flowing from stage p.

2. η_{pk} is the multiplier for the output components z_{pk}^{j2} at stage p and as it becomes the input to stage $p+1$.

3. υ_{pi} is the multiplier for the input component z_{pi}^{j3} entering the process at the beginning of stage $p+1$.

Hence, when $p = 2,3, \ldots$, the efficiency ratio for DMU_j is given as:

$$\theta_p = \left(\sum_{r=1}^{R_p} u_{pr} z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} z_{pk}^{j2}\right) \Big/ \left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3}\right)$$

(Equation 8.59)

However, since there are no inputs flowing into the first stage of the supply chain, the efficiency measure for this stage is given by:

$$\theta_1 = \left(\sum_{r=1}^{R_1} u_{1r} z_{1r}^{j1} + \sum_{k=1}^{S_1} \eta_{1k} z_{1k}^{j2}\right) \Big/ \left(\sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j}\right) \qquad \text{(Equation 8.60)}$$

Hence, the overall efficiency measure of the multistage process can be reasonably represented as a convex linear combination of the P measures, namely:

$$\theta = \sum_{p=1}^{p} w_p \theta_p \qquad \text{(Equation 8.61)}$$

Here w_p signifies the contribution of the performance of the individual stages p to the overall performance of the entire process. Azbari et al (2014) suggest that this should be the proportion of the total resources for the processes devoted to stages p and reflecting on the relative size of that stage. Hence:

$$w_1 = \sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j} / \left\{ \sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j} + \sum_{p=2}^{p} \left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3} \right) \right\}$$

(Equation 8.62)

$$w_p = \frac{\left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3} \right)}{\left\{ \sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j} + \sum_{p=2}^{p} \left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3} \right) \right\}}, p > 1$$

(Equation 8.63)

Hence the expression for overall supply chain efficiency is given by

$$\theta = \sum_{p=1}^{p} \frac{\left(\sum_{r=1}^{R_p} u_{pr} z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} z_{pk}^{j2} \right)}{\left\{ \sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j} + \sum_{p=2}^{p} \left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3} \right) \right\}}$$

(Equation 8.64)

For the NDEA model with constant returns to scale (CRS) to be converted to a variable returns to scale (VRS) the free-in-sign variable L is added in the ratio definition for each stage of the supply chain. Hence, when $p = 2,3, \ldots$, the efficiency ratio for DMU_j is given as:

$$\theta_p = \frac{\left(\sum_{r=1}^{R_p} u_{pr} z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} z_{pk}^{j2} \right) + L_p}{\left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3} \right)} \qquad \text{(Equation 8.65)}$$

This model is changed to a variable returns to scale (VRS) model via the addition of the free-in-sign variable L. Hence for stage 1 we have

$$\theta_1 = \frac{\left(\sum_{r=1}^{R_1} u_{1r} z_{1r}^{j1} + \sum_{k=1}^{S_1} \eta_{1k} z_{1k}^{j2} \right) + L_1}{\left(\sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j} \right)} \qquad \text{(Equation 8.66)}$$

Hence, the overall efficiency for a VRS model is given by:

$$\theta = \frac{\left(\sum_{r=1}^{R_p} u_{pr} z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} z_{pk}^{j2}\right) + \sum L_p}{\left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3}\right)} \qquad \text{(Equation 8.67)}$$

Hence the overall efficiency of the two stage process subject to the restrictions that the individual measures θ_p must not exceed unity, or in linear programming format:

$$\max \sum_{p=1}^{p} \left(\sum_{r=1}^{R_p} u_{pr} z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} z_{pk}^{j2} \right) + L_1 + L_2$$

Subject to

$$\left\{ \sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j} + \sum_{p=2}^{p} \left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3} \right) \right\} = 1,$$

$$\left(\sum_{r=1}^{R_1} u_{1r} z_{1r}^{j1} + \sum_{k=1}^{S_1} \eta_{1k} z_{1k}^{j2} \right) + L_1 \leq \left(\sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j} \right) \quad \forall j,$$

$$\left(\sum_{r=1}^{R_p} u_{pr} z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} z_{pk}^{j2} \right) + L_2 \leq \left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3} \right) \quad \forall j,$$

$$u_{pr}, \eta_{pk}, \upsilon_{0i}, \upsilon_{0i} > 0$$

$$L_1, L_2 \; free\ in\ sign \qquad \text{(Equation 8.68)}$$

Hence, if the overall efficiency scores for each j should not exceed unity

$$\theta = \frac{\left(\sum_{r=1}^{R_p} u_{pr} z_{pr}^{j1} + \sum_{k=1}^{S_p} \eta_{pk} z_{pk}^{j2}\right) + \sum L_p}{\left\{\sum_{i=1}^{I_0} \upsilon_{0i}\, z_{0i}^{j} + \sum_{p=2}^{p} \left(\sum_{k=1}^{S_{p-1}} \eta_{p-1k} z_{p-1k}^{j2} + \sum_{i=1}^{I_p} \upsilon_{p-1i}\, z_{p-1i}^{j3}\right)\right\}} \qquad \text{(Equation 8.69)}$$

However, by adding these last two constraints on the VRS model these are redundant and unnecessary.

8.6. Conclusion

This chapter has discussed a hybrid approach based on a combination of the Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) towards resolving the issues identified within the CFSC. The models presented in this chapter imply that many solutions are available and can be readily implemented into a data monitoring system.

Chapter Nine – A Game Theoretical Approach to Evaluating the Effectiveness of a Supply Chain Strategy

9.1. Introduction

So far in this study we have not yet considered the issues involved with information sharing, or the formation of cooperative relationships, which emerge within the supply chain. Hence, in this chapter we consider the formation of the most effective supply chain strategy between suppliers and retailers. Hence, the structure of this chapter is broken down into the following four research:

1. What approaches have already been considered towards evaluating SCM practices?
2. How do we define a supply chain strategy?
3. What is meant by the term “information sharing” and how does it help or hinder relationships between companies operating within the supply chain?
4. What is meant by the term “adaptive goal setting”?

Accordingly, the structure of this chapter is given in Figure 9.1. below:

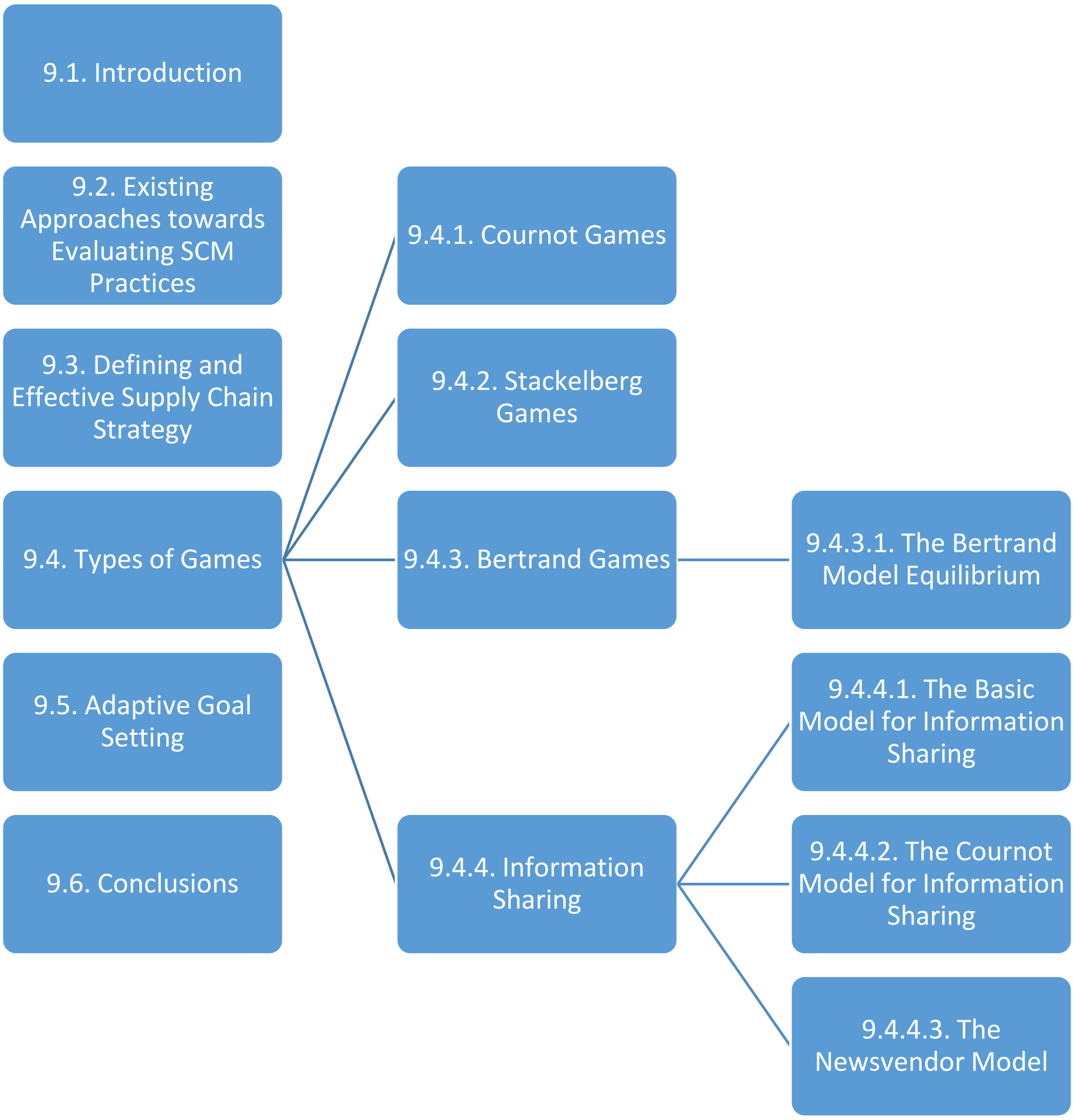

Figure 9.1. to illustrate the structure of Chapter Eight.

9.2. Existing Approaches towards Evaluating SCM Practices

Thierry et al (2010) suggest that there are three approaches to supply chain modelling:

1. Analytical methods such as queuing theory. However, this is generally impractical because the models are often too complex to be solved.

2. Physical experiments such as lab platforms or industrial pilot implementations. However, this may prove to be technically and financially difficult.
3. Monte-Carlo methods such as simulation or emulation. This is perhaps the only recourse for exploring the performance of large-scale supply chain models. In addition, simulation aids with the design and evaluation of the supply chain (Thierry et al 2010, 2).

In addition, Thierry et al (2010) state that the supply chain model is dependent upon two distinct features:

1. The degree of systemic decomposition of the supply chain model (i.e. decision system, information system, physical system);
2. The distribution level of the system (i.e. centralised or distributed). Accordingly a centralised system consists of a single information and decision system for all entities of the supply chain, whilst a distributed system is distributed over all of the elements of the supply chain (Thierry et al 2010, 3).

Thierry et al (2010) also discuss some of the advantages of running a simulation across multiple machines (ibid.). Whilst this is more complicated than running a simulation on a single computer, some of the advantages are:

1. A reduction in execution of simulation time;
2. The geographic distribution of the supply chain can be modelled more accurately;
3. Existing simulation models can be incorporated into the simulation;
4. It enhances tolerance to simulation failure (Thierry et al 2010, 4).

Some discussion of discrete event simulation is also given – of which there are two kinds:

1. Time bucket driven – where time is divided into equal periods or "buckets";
2. Event driven – where specific events drive a change of state (ibid.).

However, in event driven discrete event simulation, the supply chain simulation may become overly complicated due to the size of the supply chain and the number of events which need to be coordinated.

Some consideration is also given to the difference between simulation and emulation. Accordingly, emulation "aims at mimicking the behaviour of the physical system only" (Thierry et al 2010, 5). This means that an emulator could be constructed to test a model against normal or standardised data, but may also provide a means of evaluating the limitations of an existing system. By comparison, a simulation is an approximation of the physical system of varying degrees of complexity.

Cope et al (2007) present a list of research questions which aid with the design of the simulation:

1. Does the model take into account uncertainty?
2. Does the model represent the entire supply chain (i.e. supply chain processes, their interactions, information flow, object and material flow for the different partners involved)?
3. Is the model easy and quick to modify in order to examine different scenarios?
4. Can the model be modified to represent a "to be" state rather than an "as is" state?
5. Does the model allow parameters to be varied without requiring a lengthy modelling process?

6. Can models developed represent varying levels of detail (i.e. enterprise level, functional level, facility level)?
7. Can the models developed address decision making for supply chain design?
8. Is the model capable of analysing or implementing inventory strategies and/or the effect of varying safety stock?
9. Can the models be easily shared to enhance communication between stakeholders? (Cope et al 2007, 1893).

However, whilst these questions are used to evaluate a simulation built using the Arena 10.0 language, we can use them to assess whether all of our models are in place, whether they are over complicated or over simplified and how robust they are.

Park and Jeong (2014) present a mathematical model of the supply chain which is intended to form the basis of a software simulation. Accordingly, each stage of the supply chain is broken down into its component stages: supplier, factory, distribution centre, customer and transport. However, whilst the basis of this model is in minimising the overall cost of the supply chain, the model does not include loss functions and does not anticipate where the greatest losses are being made.

Abolhasani et al (2014) present a simulation in MATLAB to examine the efficiency of a multi-commodities consumer supply chain. The performance of the model is evaluated using the SimEvents toolbox in conjunction with the Simulink toolbox of MATLAB.

Alawneh et al (2014) develop a linear programming model of the Qatar steel manufacturing supply chain. The model is evaluated using GAMS software.

Azbari et al (2014) propose a Network DEA model (NDEA) for the evaluation of performance of the supply chain, based on a variable returns to scale (VRS) model. This is based on perceiving the supply chain as a P-stage process, i.e. that the input stage will produce a vector of p outputs, where $\mathrm{p} = 1, \dots, \mathrm{P}$.

Simon et al (2015) propose a structured methodology for evaluating SCM practices. It is based on a conceptual model of SCM proposed by Cooper et al (1997), which involves eleven referential axes of analysis established from key business processes, SCM horizontal structures, initiatives and practices. The first nine of these are related to key business processes and can be used to identify whether the company manages and integrates them with key first-tier customers and key first-tier suppliers (Simon et al 2015, 31), whilst the tenth referential axis refers to horizontal supply chain structure and is used to identify whether the company monitors the management of key business processes beyond the first-tier of key suppliers or the first-tier of key customers (Simon et al 2015, 32). The eleventh referential axis refers to SCM initiatives and practices and can be used to identify whether the company uses or intends to use these to support business process management (ibid.). The implication is that we ought to be able to express these eleven axes in formal terms, such that the whole evaluation procedure can be automated.

9.3. Defining an Effective Supply Chain Strategy

Perez-Franco et al (2011) propose a method for evaluating a firm's conceptual strategy, which is based on four evaluation criteria:

1. Support for the firm's strategic objectives;

2. Consistency among the internal elements;
3. Coverage of areas of interest;
4. Sufficiency in fulfilling expectations (Perez-Franco et al 2011, 1).

Here a supply chain strategy is defined as “the set of ideas behind the activities, decisions and choices of that firm’s supply chain, which serve as logical bridge between the supply chain operations in the field and the business strategy” (Perez-Franco et al 2011, 4). However, the problem with this definition is that it assumes a difference between supply chain strategy and business strategy, leading to circular reasoning, or the problem of infinite regress as typified by “I think that he thinks that I think…” (Cyert et al 1978, Yue et al 2006).

If we consider that the word “strategy” derives from the Greek “στρατηγία” or “strategia” to mean “office or command of a general” (OED 2016), we can demonstrate that the underlying principle behind a successful supply chain strategy is to model it using game theory. In addition, strategy is closely related to the terms “tactics” and “combinations” although both of these are achieved in relation to the overall strategy being employed (ibid.). Hence, any overall strategy should be considered in terms of many sub-strategies and alternatives, all of which need to work together in combinations for the supply chain model to function effectively. This reasoning also aids with making the supply chain more agile, but also helps to identify areas of the supply chain model which might be improved.

9.4. Types of Games

Before we consider the types of games available, we impose the limit that the games being “played” are between suppliers and retailers. Accordingly, three types of game are considered relevant to the discussion: Cournot games, Stackelberg games and Bertrand games. Each of these will be discussed in turn as follows:

9.4.1. Cournot Games

In a Cournot game (Cournot 1838) two firms compete simultaneously on the quantity of homogeneous product output they produce. Accordingly, in any given period the quantity Q which is demanded is satisfied by the equation

$$Q = Q_1 + Q_2 \qquad \text{(Equation 9.1)}$$

where Q_1 is the demand which can be satisfied by the first company and Q_2 is the demand which can be satisfied by the second company. In order to maximise its profits, each firm needs to:

1. Calculate its marginal revenue as a function of $Q_1 + Q_2$;
2. Set the marginal revenue as being equal to marginal cost;
3. Solve for this quantity, such that the optimal level of quantity for each company is a function of the other firm's quantity, i.e.

$$Q_1^* = f(Q_2) \qquad \text{(Equation 9.2)}$$

and

$$Q_2^* = f(Q_1) \qquad \text{(Equation 9.3)}$$

Graphically, the Cournot equilibrium is represented as follows:

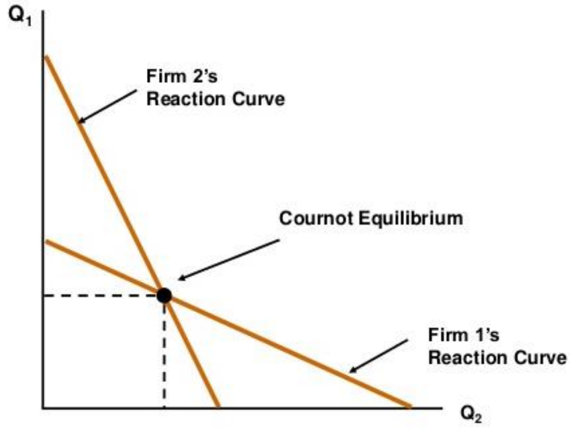

Figure 9.2. Graphical representation of a Cournot model equilibrium.

We also note that a Cournot equilibrium is equivalent to a Nash equilibrium, given that once equilibrium has been reached there is no incentive to change strategies because the payoff cannot be improved upon.

9.4.2. Stackelberg Games

In a Stackelberg game (Stackelberg 1952) two firms compete sequentially on the quantity of the output they produce of a homogeneous product. Since one of the firms "plays" first, the second firm will issue quantity Q_2 in response to the quantity Q_1 issued by the first firm. However, the Stackelberg game equilibrium is reached by one firm making a pre-emptive move to secure a larger output than the other firm, such that the other firm is forced to curtail its output.

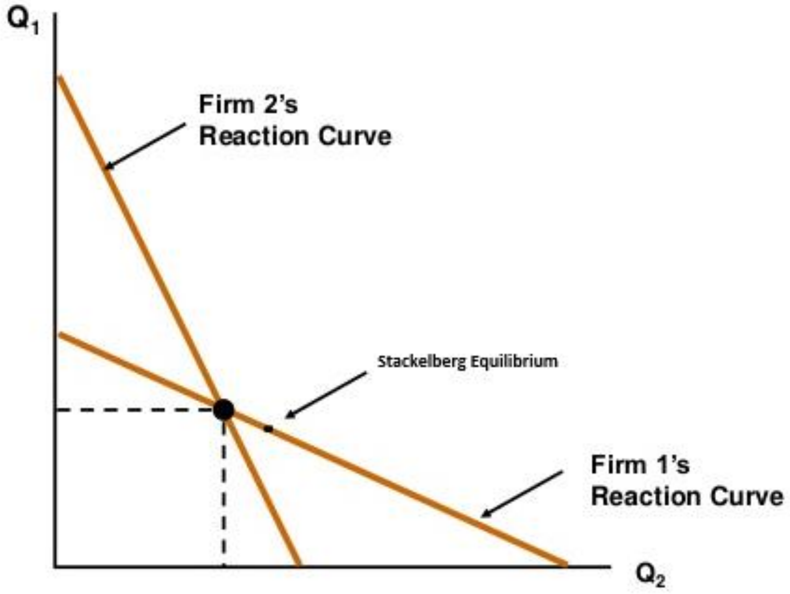

Figure 9.3. Diagram to illustrate the difference between a Stackelberg equilibrium and a Cournot equilibrium. Note that if the game is allowed to continue the response functions of firm 1 and firm 2 will coincide with a Cournot equilibrium.

Zhen et al (2006) provide a Stackelberg model where the leader is the producer and the supplier is the follower. However, if consider customer demand for specific products is what drives the supply chain (i.e. leader), the supplier must be prepared to meet this demand (i.e. follower). Hence, we can adapt the Zhen et al (2006) reasoning in terms of retailers (i.e. leaders) and suppliers (i.e. followers), given that the goal of demand forecasting is concerned with managing the transition from forecasts having a high uncertainty to customer orders having significantly less uncertainty. We can therefore begin to outline the relevant cost functions.

Firstly, we consider the model for C^R which is the cost to the retailer

$$C^R = \pi[D - d]^+ + g[d - D]^+ + pd - k[q - d]^+ \qquad \text{(Equation 9.4)}$$

Here $\pi[D-d]^+$ is the punishment cost to the retailer when the delivery amount d is less than the demand D for products, $[D-d]^+ = \max\{0, D-d\}$, $g[d-D]^+$ is the possession cost of holding products which are redundant after demand has been met, where g is the possession cost of every unit and $[d-D]^+ = \max\{0, d-D\}$, pd is the purchasing cost to the retailer, p is the price of every unit part, $k[q-d]^+$ is the alterable punishment cost paid by the supplier for the purpose of inspiring the retailer when the supplier cannot meet the demand of the retailer, k is the unit punishment cost for the supplier set up by the retailer and $[q-d]^+ = \max\{0, q-d\}$.

When the retailer sends out order quantity q only the distribution function $F(\alpha)$ and the density function $f(\alpha)$ are known (Hence, a game of incomplete information). However, we can anticipate that the total cost to the retailer will depend upon order quantity q, unit punishment cost k for the supplier and extra supply capability Δ set up by the supplier. Hence, the expected total cost to the retailer is

$$E(C^R) = \pi \int_{0}^{min\{x(q,\Delta),y(\Delta)\}} \big(D-(\alpha C+\Delta)\big) f(\alpha) d\alpha +$$

$$\pi(D-d) \int_{x(q,\Delta)}^{1} f(\alpha) d\alpha 1_{\{D>q\}} + g \int_{y(\Delta)}^{x(q,\Delta)} \big(D-(\alpha C+\Delta)\big) f(\alpha) d\alpha +$$

$$g(q-D) \int_{x(q,\Delta)}^{1} f(\alpha) d\alpha 1_{\{D<q\}} + p \int_{y(\Delta)}^{x(q,\Delta)} (\alpha C+\Delta) f(\alpha) d\alpha +$$

$$pq \int_{x(q,\Delta)}^{1} f(\alpha) d\alpha - k \int_{y(\Delta)}^{x(q,\Delta)} \big(q-(\alpha C+\Delta)\big) f(\alpha) d\alpha \qquad \text{(Equation 9.5)}$$

Where

$$y(\Delta) = \frac{(D - \Delta)}{C}, \qquad \text{(Equation 9.6)}$$

$$x(q, \Delta) = \frac{(q - \Delta)}{C} \qquad \text{(Equation 9.7)}$$

and

$1_{\{D<q\}}$ is defined as the indication function

$$1_{\{D<q\}} = \begin{cases} 1 & if\ D > q \\ 0 & otherwise \end{cases} \qquad \text{(Equation 9.8)}$$

Next, we consider the profit model of the supplier

$$P_{q,k}^{S} = pd - h[\alpha C + \Delta - q]^{+} - w\Delta - k[q - d]^{+} \qquad \text{(Equation 9.9)}$$

Here $h[\alpha C + \Delta - q]^{+}$ is the possession cost for unsold items under overcapacity of the supplier, h is the unit possession cost, $w\Delta$ is the cost of extra throughput set up by the supplier in order to meet the order quantity of the retailer.

When $f(\alpha)$ is known the expected profit model of the supplier is given by

$$E(P^{S}) = p \int_{0}^{x(q,\Delta)} (\alpha C + \Delta) f(\alpha) d\alpha + pq \int_{x(q,\Delta)}^{1} f(\alpha) d\alpha -$$

$$h \int_{x(q,\Delta)}^{1} (\alpha C + \Delta - q) f(\alpha) d\alpha - w\Delta - k \int_{0}^{x(q,\Delta)} \big(q - (\alpha C + \Delta)\big) f(\alpha) d\alpha \qquad \text{(Equation 9.10)}$$

This equation includes the anticipated income, anticipated possession costs, the practical cost of setting up extra supply chain capability and the anticipated punishment cost.

9.4.3. Bertrand Games

A Bertrand game (Bertrand 1883) can be thought of as a development of a Stackelberg game, with the exception that firms are competing over the lowest possible price rather than for the highest available quantity. Accordingly, consumers buy from the firm with the lowest price. Hence, equilibrium is reached according to the equation

$$P = MC \qquad \text{(Equation 9.11)}$$

where P is the retail price and MC is the marginal cost. Hence, for two firms involved in a Bertrand game,

$$P_1 = P_2 = MC \qquad \text{(Equation 9.12)}$$

The general model for a Bertrand game is given by Boone et al (2012). Accordingly, if we consider a market with n firms which compete to sell exactly one unit, where $n = 2, 3$. The reservation price of the buyer is 100. The firm selling at the lowest price in the market will sell one unit whilst the remaining firms will sell no units. If two firms sell at the lowest price then each firm will sell half a unit, whilst if three firms sell at the lowest price then each firm will sell a third of a unit. The profit Π_i of firm i in each round will be

$$\Pi_i = \frac{(p_i - c_i)d_i}{N} \qquad \text{(Equation 9.13)}$$

Where $p_i \in \{1,2, \dots ,100\}$ is the price chosen by firm i, N is the number of firms offering the lowest price in the market, $d_i = 1$ if p_i is the lowest price in the market and $d_i = 0$ otherwise. We also note that firm i has a constant marginal cost given by c_i.

9.4.3.1. The Bertrand Model Equilibrium

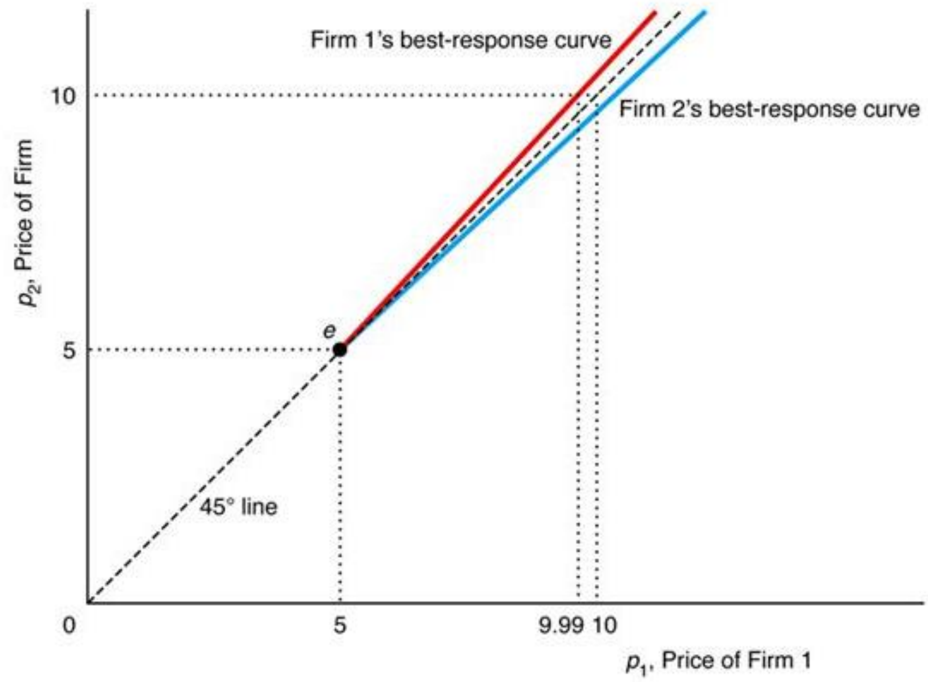

Figure 9.4. Diagram to illustrate a Bertrand equilibrium based on Perloff (2014). Note that the desire of each firm to undercut will effectively reduce to a Cournot equilibrium if the game is played long enough.

The following overview of the Bertrand equilibrium is based on Bagh (2010). Accordingly, if we consider that $q = D(p)$ is the market demand when the market price is p, $D^i{}_T(p)$ is the market share of firm i when all firms post the same price p, and C_i is the cost function of firm i.

We first consider the symmetric case for when $D^i{}_T = D_T$ and $C_i = C$ for all i, and let $p = (p_i, \dots, p_n)$ be the vector of prices which signify the Bertrand equilibrium. When a firm deviates from this vector p by increasing its price, such that $p' > p$, that firm will receive zero demand. However, when a firm deviates by lowering its price such that $p' < p$ the firm will receive the entire demand $D(p')$.

Hence,

1. There exists a price p^s such that $D(p) = 0$ for all $p \geq p^s$ and D is decreasing on $[0, p^s]$. What this infers is that there is a lowest possible price for the supplier to trade at, below which the supplier would be making a loss. Hence, the more a firm lowers its production costs the lower p^s will be, which will give the company a greater share of market demand.
2. For all $p \in [0, p^s)$, $0 < D_T(p)$, D_T is decreasing on $[0, p^s]$ and $D_T(p^s) = 0$. What this infers is that market share ceases to be profitable once the price falls below the p^s threshold.
3. C is continuous, increasing and convex and without loss of generality, it is assumed that $C(0) = 0$.

   Let $\Pi(p) = pD(p) - C\big(D(p)\big)$, $\widehat{\Pi}(p) = pD_T(p) - C\big(D_T(p)\big)$ and $\Delta\Pi(p) = \Pi(p) - \widehat{\Pi}(p)$.
4. There exist prices $p, p' \in (0, p^*)$ such that $\widehat{\Pi}(p) > 0$, $\Pi(p') > 0$.

We can now define three threshold prices as follows:

$$p^0 = inf\{p|0 \leq p < p^m \; and \; \widehat{\Pi}(p) \geq 0\} \qquad \text{(Equation 9.14)}$$

$$p^{00} = inf\{p|0 \leq p < p^m \; and \; \Pi(p) \geq 0\} \qquad \text{(Equation 9.15)}$$

$$p^* = sup\{p|0 \leq p \leq p^m \; and \; \Delta\Pi(p) \leq 0\} \qquad \text{(Equation 9.16)}$$

5. $\widehat{\Pi}(p) = 0$ and $\widehat{\Pi}(p) = 0$ have solutions in $(0, p^m)$.
6. The cost function C is strictly convex.

Two theorems are proposed:

1. For any $p \in [p^0, p^*]$, $p = (p_i, \ldots, p_n)$ is an equilibrium. In addition, if $p \in [p^0, p^*]$ then profits are strictly positive.
2. A Bertrand game has a continuum of symmetric equilibria with strictly positive profits.

For asymmetric Bertrand games, the following theorem is proposed:

1. If $p \in \cap^I{}_{i=1} (p^0, p^*)$ then $p = (p_i, \ldots, p_n)$ is a symmetric equilibrium with strictly positive profits.

What this infers is that “as long as the asymmetry is not too severe” (Bagh 2010, 279), the intervals (p^0, p^*) will have a non-empty section. Hence, it is possible to find a Bertrand equilibrium for the asymmetric case.

9.4.4. Information Sharing

Given that the supply chain can be thought of as a collection of independent profit-maximising companies, the implication is that each of these firms will be better off sharing information than by concealing it (Shamir 2012, 352). However, there are a number of issues with information sharing which need to be considered:

1. There is often tension between overall efficiency of the supply chain and self-interest of the companies involved (ibid.).
2. Accuracy of the information cannot always be verified, leading to forecasting errors (ibid.).
3. Similarly, when a company shares information with its suppliers, there is a high risk of leakage of important information which may have a knock-on effect towards a company's business strategy (ibid.).

In order to resolve these issues, several strategies need to be considered, including:

1. Horizontal information sharing – where information is only shared amongst retailers and not with the suppliers;
2. Vertical (or Public) information sharing – where information is shared between retailers and suppliers.

However, Shamir (2012) also suggests that information sharing is based upon one of two equilibria:

1. Informative equilibrium – this is where retailers share the value of their observed signal;
2. Quasi-informative equilibrium – this is where retailers share only an interval within their observed signal (Shamir 2012, 357).

Hence, in practice, the game between retailers and suppliers will be based on partial or incomplete data.

9.4.4.1. The Basic Model for Information Sharing

From (Shamir 2012, 354, 355) the basic model for information sharing is based on a Bertrand model game between suppliers and retailers. Accordingly, a supplier provides product i to n retailers at a wholesale price w per unit. The retailer further processes the product (i.e. a supplier may be supplying ingredients to a restaurant). It is assumed that all firms are risk neutral and wish to maximise their expected profits. Retailers are then said to be engaged in a Bertrand price competition within the consumer market with a demand function:

$$q_i = a + \theta - (1+\gamma)p_i + \frac{\gamma}{n-1}\sum_{j=1, j\neq i}^{n} p_j \quad \forall i = 1, \dots, n \qquad \text{(Equation 9.17)}$$

Where q_i is the demand function for product i, p_i is the price set by the retailer, a is the known part of the potential market size, θ is the uncertain part of the market size, such that the expected value of this uncertain market $E[\theta] = 0$ and $Var(\theta) = \sigma^2$ drawn from a continuous distribution over a finite support $[\underline{\theta}, \bar{\theta}]$. For a given price p_i demand for product i is influenced by the average price set by $n-1$ retailers. Products are assumed to be imperfect substitutes and γ signifies the degree of substitution, where $\gamma \geq 0$. If $\gamma = 0$ demand for product i is independent of the retail prices set by the other retailers, and each retailer has a monopoly within its own market. However, a higher degree of γ signifies a high degree of substitution and a greater level of intensity of competition amongst retailers. In addition to the wholesale price w per unit, retailers also incur an identical constant marginal cost for customisation which is normalised to zero.

The retailer's profit is given by

$$\pi_i(p_i, \boldsymbol{p}_{-i}, w) \triangleq \left(a + \theta - (1+\gamma)p_i + \frac{\gamma}{n-1}\sum_{j=1, j\neq i}^{n} p_j\right)(p_i - w) \quad \text{(Equation 9.18)}$$

The supplier's profit is given by

$$\pi_{Supplier}(\boldsymbol{p}, w) \triangleq \sum_{i=1}^{n}\left[\left(a + \theta - (1+\gamma)p_i + \frac{\gamma}{n-1}\sum_{j=1, j\neq i}^{n} p_j\right)\right] w \quad \text{(Equation 9.19)}$$

Total supply chain profit is given by

$$\pi_{SC}(\boldsymbol{p}, w) \triangleq \sum_{i=1}^{n}\left[\left(a + \theta - (1+\gamma)p_i + \frac{\gamma}{n-1}\sum_{j=1, j\neq i}^{n} p_j\right)p_i\right] \quad \text{(Equation 9.20)}$$

Where

$$\boldsymbol{p} = (p_1, \dots, p_n)$$

$$\boldsymbol{p_{-i}} = (p_1, \dots, p_{i-1}, p_{i+1}, \dots, p_n)$$

We then consider the information structure. Accordingly, at time $t = 0$ the supplier and retailers have some knowledge of the uncertain demand θ. Each retailer obtains a signal Y_i about θ and the signals are assumed to be independent and identically distributed (i.i.d.) conditional on θ. In addition, $E[Y_i|\theta] = \theta$ where $i = 1, \dots, n$ and $E[\theta|Y_1, \dots, Y_n] = \sum_{i=1}^{n} \alpha_i Y_i$, where α_i is a constant for every i. In addition, $s \triangleq E[Var(Y_i|\theta)]/\sigma^2$ is the expected precision of the common prior relative to signal accuracy. If $K \subseteq N$is a subset of retailers, where $|K| = k$ and the set of their signals is given by $\boldsymbol{Y}_k$, this information structure implies:

$$E[\theta|\boldsymbol{Y}_k] = \frac{1}{s+k}\sum_{i\in K} Y_i,$$

$$E\left[Y_j|\boldsymbol{Y}_k\right] = E[\theta|\boldsymbol{Y}_k] \quad \text{where } j \not\ni K, \quad \text{(Equation 9.21)}$$

$$E\left[Y_l|Y_j,\boldsymbol{Y}_k\right]=E\left[\theta|Y_j,\boldsymbol{Y}_k\right]=\frac{(k+s)E[\theta|\boldsymbol{Y}_k]+Y_j}{k+s+1} \qquad \text{(Equation 9.22)}$$

where $l, j \not\ni K$ and $l \neq j$,

$$E\left[E\left[\theta|Y_j,\boldsymbol{Y}_k\right]|\boldsymbol{Y}_k\right]=E[\theta|\boldsymbol{Y}_k] \text{ where } j \not\ni K, \qquad \text{(Equation 9.23)}$$

$$E\left[Y_iY_j\right]=\sigma^2 \text{ where } i\neq j, \qquad \text{(Equation 9.24)}$$

$$E\left[{Y_i}^2\right]=\sigma^2(s+1) \qquad \text{(Equation 9.25)}$$

From this information structure it is possible to construct models for horizontal and vertical information sharing.

Accordingly, the horizontal information sharing model for a retailer's profit is given as:

$$\pi_i(k)=\left(a+E[\theta|\boldsymbol{Y}_k,Y_i]-(1+\gamma)p_i+\frac{\gamma}{n-1}\sum_{j=1,j\neq i}^{n}E\left[p_j|\boldsymbol{Y}_k,Y_i\right]\right)(p_i-w)$$

(Equation 9.26)

However, the model for vertical sharing simplifies the wholesale price w to

$$w=\frac{a+E[\theta|\boldsymbol{Y}_k]}{2} \qquad \text{(Equation 9.27)}$$

Hence, the expression for (p_i-w) becomes the condition (Equation 9.28):

$$(p_i-w)=\begin{cases}\dfrac{1}{2+\gamma}\left[\dfrac{a+E[\theta|\boldsymbol{Y}_k]}{2}\right]^2 & for\ i\in K\\[2ex] \dfrac{1}{2+\gamma}\left[\dfrac{a+E[\theta|\boldsymbol{Y}_k]}{2}+\alpha_k(Y_i-E[\theta|\boldsymbol{Y}_k])\right]^2 & for\ i\notin \mathrm{K}\end{cases}$$

where α_k is given by

$$\alpha_k = \frac{(2+\gamma)(n-1)}{2(1+\gamma)(k+s+1)(n-1)-\gamma(n-k-1)} \qquad \text{(Equation 9.28)}$$

(See Shamir et al 2012, 362)

Hence, the retailer's conditional expected profit is given by

$$E[\pi_i|\boldsymbol{Y}_k] = \frac{1+\gamma}{(2+\gamma)^2}\left[\frac{a+E[\theta|\boldsymbol{Y}_k]}{2}\right]^2 \; for\ i \in K \qquad \text{(Equation 9.29)}$$

$$E[\pi_i|\boldsymbol{Y}_k, Y_i] = \frac{1+\gamma}{(2+\gamma)^2}\left[\frac{a+E[\theta|\boldsymbol{Y}_k]}{2} + \alpha_k(Y_i - E[\theta|\boldsymbol{Y}_k, Y_i])\right]^2 \; for\ i \notin \mathrm{K} \qquad \text{(Equation 9.30)}$$

However, if we take expectations over realisations, the retailer's ex-ante profit in the public truthful setting (i.e. if the retailer chooses to share information) is given by

$$\Pi_i^{PT}(k) = \frac{1+\gamma}{4(2+\gamma)^2}\left[a^2 + \frac{k}{k+s}\sigma^2\right] \; for\ 1 \le k \le n \qquad \text{(Equation 9.30)}$$

This is compared to the retailer's ex-ante profit for not sharing his demand information

$$\overline{\Pi}_i^{PT}(k) = \frac{1+\gamma}{4(2+\gamma)^2}a^2 + \frac{1+\gamma}{4(2+\gamma)^2}\,\frac{k}{k+s}\sigma^2$$

$$+\frac{(1+\gamma)(\alpha_k)^2(k+1+s)s}{(2+\gamma)^2(k+s)}\sigma^2$$

$$for\ 0 \le k \le n-1 \qquad \text{(Equation 9.31)}$$

Hence,

$$\overline{\Pi}_i^{PT}(k) \ge \Pi_i^{PT}(k) \qquad \text{(Equation 9.32)}$$

Hence, the retailer is better off for not sharing his demand information publically. This is to be anticipated, since we have already demonstrated that retailers and suppliers are engaged in a Stackelberg game in which retailers “lead” and suppliers “follow”.

However, the supplier’s ex-ante profit based on information sharing is given by

$$\Pi_{Supplier}^{PT}(k) = \frac{n(1+\gamma)}{4(2+\gamma)}\left[a^2 + \frac{k}{k+s}\sigma^2\right], \ \ for\ k = 0,1,\dots,n \qquad \text{(Equation 9.33)}$$

Hence, a supplier becomes better off as more information is revealed. Indeed, we notice that the equation for $\Pi_{Supplier}^{PT}(k)$ is practically the same as that for $\Pi_i^{PT}(k)$ in the case that $n = 1$.

We should then consider that since wholesale prices become simplified and supplier’s profits increase with information sharing that a Cournot game model might be the optimal strategy for suppliers to play.

9.4.4.2. Cournot Model for Information Sharing

The following model is developed from (Zhou et al 2016, 3, 4) in terms of how suppliers can adopt a Cournot game model and decide how much information they wish to share with other suppliers within the supply chain.

Each supplier i receives a sample ε of the demand information and can choose to share some of this knowledge. This is based on n_i observations, denoted by

$$N_i = \{\varepsilon + u_{ik} | k = 1, \dots, n_i\} \qquad \text{(Equation 9.34)}$$

where $\{u_{ik}|i = 1,2; k = 1, \dots, n_i\}$ are independent and identically distributed (i.i.d.) with mean zero and standard deviation of σ_u and are independent of ε. If Y_i is the sample mean of N_i as the private signal of supplier i, then Y_i is an unbiased estimator of ε. Hence, we have

$$E\big[Var[Y_i|\varepsilon]\big] = \frac{{\sigma_u}^2}{n_i} \qquad \text{(Equation 9.35)}$$

However, an extreme case is

$$Var[Y_i|\varepsilon] = 0 \qquad \text{(Equation 9.36)}$$

Hence, we assume

$$E\big[Var[Y_i|\varepsilon]\big] > 0 \qquad \text{(Equation 9.37)}$$

We then define

$$t_i = \frac{\sigma^2}{E\big[Var[Y_i|\varepsilon]\big]} \qquad \text{(Equation 9.38)}$$

Before observing the signal, each supplier i is committed to sharing a subset of $K_i \subseteq N_i$ observations. Hence, the number of observations is given by N_i/K_i. If x_i and y_i are sample means of the subset N_i/K_i and the shared subset K_i. Hence the observations of each supplier i can be divided into two parts. Hence, we define the level of information each supplier i chooses to share as

$$\tau_i = \frac{\sigma^2}{E\big[Var[y_i|\varepsilon]\big]} \qquad \text{(Equation 9.39)}$$

We also note that t_i and τ_i are directly proportional to sample sizes. Hence, if $\tau_i = t_i$, there is complete information sharing, whilst if $\tau_i \in (0, t_i)$ there is partial information sharing.

Hence, after sharing the group purchasing organisations (GPOs) will have the shared information (y_1, y_2) and each supplier i still holds his private information Y_i or (x_i, y_i).

The information structure in this model is based on the assumptions that:

1. $E[y_i|\varepsilon] = E[x_i|\varepsilon] = \varepsilon \quad for\ i = 1,2;$
2. $E[\varepsilon|Y]$ is affine in Y for any subset $Y \subseteq \{y_1, y_2, x_1, x_2\}$
3. $\{y_1, y_2, x_1, x_2\}$ are independent and conditional on ε.

Y_i can be linearly divided by y_i and x_i, such that

$$Y_i = \frac{\tau_i}{t_i} y_i + \frac{t_i - \tau_i}{t_i} x_i \qquad \text{(Equation 9.40)}$$

Hence,

$$E[\varepsilon|Y_i] = E\left[Y_j|Y_i\right] = \frac{t_i}{t_i + 1} Y_i \qquad \text{(Equation 9.41)}$$

$$E[\varepsilon|y_i] = E\left[y_j|y_i\right] = \frac{t_i}{t_i + 1} Y_i \qquad \text{(Equation 9.42)}$$

$$E[\varepsilon|Y_1, Y_2] = \frac{t_1 Y_1 + t_2 Y_2}{t_1 + t_2 + 1} \qquad \text{(Equation 9.43)}$$

$$E[\varepsilon|y_1, y_2] = \frac{\tau_1 y_1 + \tau_2 y_2}{\tau_1 + \tau_2 + 1} \qquad \text{(Equation 9.44)}$$

$$E[Y_i|y_1, y_2] = \frac{\tau_i}{t_i} y_i + \frac{t_i - \tau_i}{t_i} E[x_i|y_1, y_2] \qquad \text{(Equation 9.45)}$$

In addition, we can verify that

$$E\left[{Y_i}^2\right] = E[Y_i y_i] = \frac{t_i + 1}{t_i} \sigma^2 \qquad \text{(Equation 9.46)}$$

$$E[{y_i}^2] = \frac{\tau_i + 1}{\tau_i}\sigma^2 \qquad \text{(Equation 9.47)}$$

Hence,

$$E[Y_i Y_j] = E[y_i y_j] = E[Y_i y_j] = E[\varepsilon Y_i] = E[\varepsilon y_i] = E[\varepsilon^2] = \sigma^2 \qquad \text{(Equation 9.48)}$$

9.4.4.3. The Newsvendor Model

An additional model related to the Cournot game model is that of the newsvendor model. The following précis is developed from Govindan et al (2013) and Cachon (2003). Here we treat the newsvendor model as an effective method for achieving a Cournot equilibrium between retailers and suppliers. Accordingly, a retailer must make a decision on ordering q amount of stock before the start of the selling season. The demand $D > 0$ has a distribution function F and a density function f, where $F(0) = 0$, $\bar{F}(x) = 1 - F(x)$, and $\mu = E[D]$. c_s is the supplier's production cost, c_r is the retailer's marginal cost and the retail price p must satisfy the constraint $c_s + c_r < p$. In addition, g_r is the good will loss for each unit of demand the retailer does not satisfy and g_s is the good will loss for each unit of demand the supplier does not satisfy. υ is the net salvage value for leftover inventory at the end of the selling season. If we consider $S(q)$ is the expected sales and T is the transfer payment from retailer to supplier, the profit functions are given as:

$$\pi_r(q) = (p - \upsilon + g_r)S(q) - (c_r - \upsilon)q - g_r\mu - T \qquad \text{(Equation 9.49)}$$

$$\pi_s(q) = g_s S(q) - c_s q - g_s\mu + T \qquad \text{(Equation 9.50)}$$

Total supply chain profit for the newsvendor model is given as:

$$\Pi(q) = \pi_r(q) + \pi_s(q) \qquad \text{(Equation 9.51)}$$

Hence, we can see how this profit model can be constructed from the standard model for a Cournot game, i.e. equation 1:

$$Q = Q_1 + Q_2$$

However, if $c = c_r + c_s$, and $g = g_r + g_s$

$$\Pi(q) = (p - v + g)S(q) - (c - v)q - g\mu \qquad \text{(Equation 9.52)}$$

There are a number of contract clarifications associated with the newsvendor model, which are given as follows:

1. Classification based on transfer payments – where participants endorse contractual incentives such that every firm's objective is aligned to the supply chain's objective.
2. Classification based on inventory risk allocation – these are based on either "push" or "pull" contracts as follows:
    a. In "push" contracts the retailer manages the risk given that he buys stock without having any demand information.
    b. In "pull" contracts the supplier manages the risk given that he replenishes stock on the basis of customer demand.
3. Advance-purchase discount contracts – this is based on having two wholesale prices;
    a. A regular price for goods ordered during the selling season. In this case the supplier holds the risk of holding inventory.
    b. A discounted price for goods ordered before the start of the selling season. In this case it is the retailer who holds the risk.

However, given that the CFSC is concerned with products which have very short shelf lives, we might also consider a fourth type of contract clarification – namely that of a late or last-minute discount contract. Accordingly, a retailer may consider buying discounted products because they are reaching the end of their shelf lives. However, the risks involved with last-minute purchasing are twofold:

1. A percentage of the products (i.e. fruit and vegetables) may already have begun to decay and are no longer fit for human consumption, in which case the retailer has lost money on products which cannot be sold.
2. A supplier must risk holding onto stock based on the assumption that he can find a buyer before the products (or a significant percentage) have decayed, in which case the supplier risks losing money because he cannot find a buyer before the products' expiration date has been reached.

9.5. Adaptive Goal Setting

Axelrod (1984) demonstrated that in computer simulations of games in which rational players repeated play, cooperative behaviour patterns emerged. Yet in games involving single play this behaviour did not emerge. Therefore, if people know they will be interacting over long periods of play they are more likely to offer strategies involving cooperation. Yet from this chapter we have also demonstrated how Stackelberg and Bertrand model equilibria will tend towards a Cournot model equilibrium if the game is played indefinitely. Hence, the implication is that we can employ adaptive goal setting in order to improve our supply chain strategy on a continuous basis.

In particular, Rahwan et al (2007) propose the following lemma:

$$\text{At any time } t\ T_{\Lambda(i)} \subseteq T_{\Lambda(i),cgoals_j^t} \qquad \text{(Equation 9.53)}$$

(Rahwan et al 2007, 119)

This means that at any time the number of goals established by the decision maker within a bounded rational system remains incomplete. This is a paraphrasing of Harsanyi (1968)'s reasoning that if G^* is the "best possible" game or strategy which can be played based upon the information available then $G^* \subseteq G$, where $G = \{G_1, \dots, G_n\}$ is the set of best possible games which can be played. Hence, adaptive goal setting is concerned with finding the optimum game or strategy as the information available improves.

In addition, Baresi et al (2010) state how adaptive models guide the definition of the supervision directives that have to be embedded in the process (Baresi et al 2010, 119). These comprise of:

1. Monitoring – to decide when adaptation must be carried out, and
2. Recovery – in order to change the running instance or the process itself.

Data must be collected for each directive in order to determine whether it must be applied. The supervision infrastructure provides probes to stop and resume the process execution when needed for monitoring and adaptation purposes, monitoring components to analyse retrieved data and adaptors to apply recovery actions (ibid.).

However, Baresi et al (2010) also state how recovery directives require the inspection of strategies associated with the adaptive goals, which can lead to conflict due to the following:

1. Conflicts among strategies that can be applied on the same goal at the same time due to overlapping of additional conditions. Their policy for dealing with this is to allow the strategy with higher severity to be triggered before the others.
2. Conflicts among strategies applied for the benefit of conflicting goals (i.e. where the conflict is specified in the goal model). Conflicts of this type are resolved through the goal model.
3. Conflicts among strategies that may generate an incoherent process if applied at the same time

Cheng et al (2009) detect the reasons or threats that may cause uncertainty in the satisfaction of goals and propose three strategies for their mitigation:

1. Add new functionality
2. Tolerate uncertainty
3. Switch to a new goal model

However, Baresi et al (2010) claim that the Cheng et al (2009) method does not constrain the ways a goal model can be modified but can have different objectives and severity (Baresi et al 2010, 122). Baresi et al (2010) also state that very few papers have focused on reconciliation mechanisms when requirements are violated.

9.6. Conclusions

This chapter has discussed a range of issues associated with supply chain strategy. It has indicated that supply chain management issues (i.e. with demand or pricing considerations) generally fall into three types of games: Cournot games, Stackelberg games and Bertrand games. However, the main finding of the discussion is that multiple games may be in operation between suppliers and retailers. As a consequence, the issue of information (i.e. demand and/or pricing considerations) is a very (commercially) sensitive area. Accordingly, whilst suppliers become better off the more demand information is shared, this is because suppliers and retailers are effectively engaged in a Stackelberg game in which retailers "lead" and suppliers "follow". However, a discussion of the newsvendor model, which is based upon locating a Cournot equilibrium between retailers and suppliers, suggests that it is more beneficial for suppliers and retailers to work together more closely. We have also demonstrated that since all three game models will naturally tend towards a Cournot equilibrium, a successful supply chain strategy will depend upon the longevity of the working relationships between suppliers and retailers.

Chapter Ten – Conclusions and Future Research

10.1. Introduction

The structure of this chapter is given in figure 10.1.

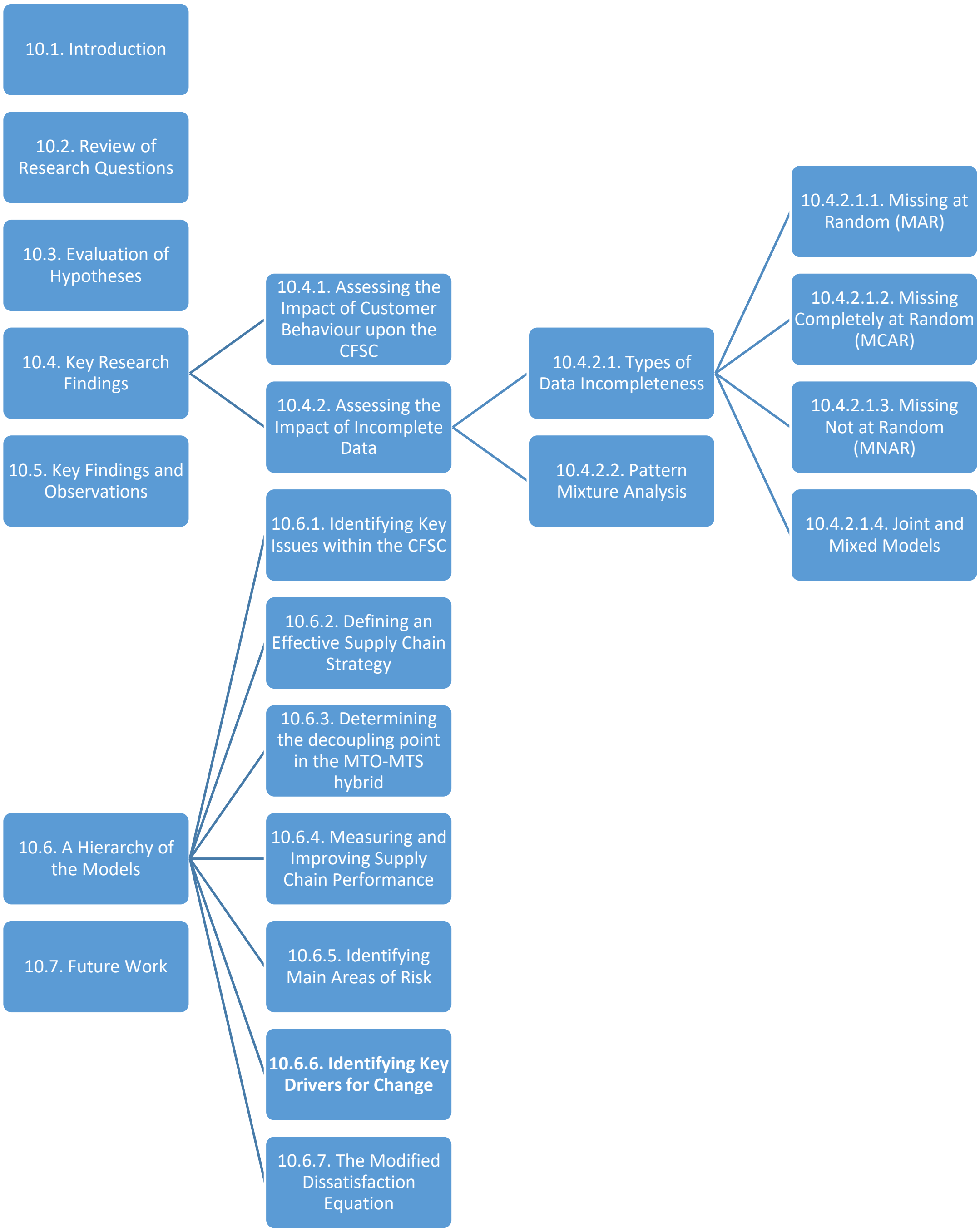

Figure 10.1. The Structure of Chapter Ten.

10.2. Review of Research Questions

As a reminder, the following six research questions were posed in Chapter One to form the basis of the literature search:

7. What are the key issues involved within the chilled food supply chain (CFSC)?
8. How do we implement a philosophy of continuous improvement as a means of reducing waste or variation within the CFSC?
9. How do we anticipate the main areas of uncertainty so that the optimum amount of waste or variation can be reduced within the CFSC?
10. How do we measure and improve the performance of the existing supply chain model?
11. What are some of the issues involved with information sharing between suppliers and retailers?
12. How can we implement more sustainable practices into the CFSC in order to reduce food losses and wastage (FLW) on a global scale?

We are now in a position to review these questions, in order to determine whether or not they have been answered adequately within the literature search.

1. What are the key issues involved within the chilled food supply chain (CFSC)?

This question formed the basis of Chapter Two, where the key issues within the CFSC were identified within the literature. Specifically, the following four key issues were identified because they have the potential to be transformed by the impact of Industry 4.0:

1. Technological challenges within the CFSC;
2. Demand forecasting;

3. Customer satisfaction;
4. Price fluctuation.

However, the technological challenges within the CFSC were further broken down into:

1. Implementation of Industry 4.0;
2. Temperature and energy monitoring;
3. Quality and maintaining quality;
4. Transportation and logistics;
5. Food safety and traceability
6. Shelf life monitoring;
7. Food waste monitoring.

Yet we also demonstrated under section 1.4. that Industry 4.0 will impact upon the technological challenges identified. Hence, even though other issues may be present within the CFSC, these are considered as secondary to the seven categories initially identified.

2. How do we implement a philosophy of continuous improvement as a means of reducing waste or variation within the CFSC?

This question was discussed in Chapter Three in relation to the Lean philosophy of continuous improvement. This chapter also compared and contrasted “push” and “pull” system strategies, but illustrated that since the concept of a purely “pull-driven” is an ideal state derived from the Lean philosophy, we can only ever manage the reduction of waste and/or variation in line with the position of the MTO-MTS decoupling point. Hence, acceptable thresholds for wastage and/or variation need to be established, which can be further reduced in line with a philosophy of continuous improvement.

3. How do we anticipate the main areas of uncertainty so that the optimum amount of waste or variation can be reduced within the CFSC?

In Chapter Four we discussed uncertainty theory and formal undecidability, which in turn led to the development of the “bounded rational” DEA model. However, in Chapter Five we considered that uncertainty within the CFSC falls into one of four categories: technological innovation; process design; product development; risk management (Rodgers 2011). Chapter Four also introduced the Cunningham equation, which provides a measure of the overall perceived risk to the customer. Hence, because the Cunningham equation is itself derives from the basic game theory model, we concluded that it should be possible to benchmark the overall perceived risk to the customer in terms of the categories identified by Mitchell (1998).

4. How do we measure and improve the performance of the existing supply chain model?

This question was discussed in Chapter Five. However, in addition to the inherent uncertainties of the supply chain discussed in Chapter Four, the SCOR model itself contains many inherent uncertainties, including:

1. The fact that new performance metrics will always be needed as the business model develops and expands, leading to unnecessary over-complications and duplications;
2. Certain performance metrics may be categorised under more than one of the four levels “Plan”, “Source”, “Make” and “Deliver”, which also leads to over-complications.

3. From Stone (2011) the following weaknesses were also identified within the SCOR model:
    a. A lack of a network-orientated logistics-controlling mechanism;
    b. The current model does not address sales and marketing, product development, research and development and some elements of post-delivery customer support;
    c. Target setting does not consider multiple perspectives of the problem owners and neither does it readily accommodate the time phasing of objectives.

Hence, we discussed some alternatives to the SCOR model. We also suggested that the studies of Joshi et al (2011) and Shashi and Singh (2015) could be used to form the basis of an alternative to the SCOR model, but one which was based on belief degrees (i.e. from uncertainty theory), such that the new model would be based on an uncertain or "bounded rational" hybrid AHP-DEA model.

Two additional research questions were added once the initial investigation was completed:

5. What are some of the issues involved with information sharing between suppliers and retailers?

This question was addressed in Chapter Eight, where we suggested that supply chain management (SCM) is based upon three types of games:

1. Cournot games, where two firms compete simultaneously on the quantity of homogeneous product output they produce;

2. Stackelberg games, where two firms compete sequentially on the quantity of the output they produce of a homogeneous product;
3. Bertrand games, where firms are competing over the lowest possible price rather than for the highest available quantity.

We also introduced information sharing, which effectively falls into two categories:

1. Horizontal information sharing, where information is only shared amongst retailers and not with the suppliers;
2. Vertical (or public) information sharing, where information is shared between competing retailers and suppliers.

However, from Shamir (2012) it was suggested that information sharing is based upon one of two equilibria:

1. Informative equilibria, where retailers share the value of their observed signal;
2. Quasi-informative equilibria, where retailers share only an interval within their observed signal.

Hence, any game between retailers and suppliers will be based on partial or incomplete data.

From Shamir (2012) it was shown that both the retailer's expected profit and the retailer's ex-ante profit will be greater in the case where the retailer chooses not to share his information with the supplier. This outcome is consistent with the concept that retailers and suppliers are engaged in a Stackelberg model game, in which retailers "lead" and suppliers "follow". Accordingly, we also demonstrate that a supplier will become better off the more information is revealed by the retailer.

We also introduced the topic of adaptive goal setting. In particular, from Rahwan et al (2007) we noted that at any time the number of goals established by the decision maker within a bounded rational system remains incomplete. Hence, we discussed some methods for improving the goals (i.e. adaptive goal setting) as the level of information available increases. Hence, adaptive goal setting provides a feasible approach to optimising supply chain strategy.

6. How can we implement more sustainable practices into the CFSC in order to reduce food losses and wastage (FLW) on a global scale?

This question was discussed in Chapter Nine, which led to the development of the modified dissatisfaction equation. Accordingly, this study has largely been concerned with micro-level causes of FLW since we have been examining how close monitoring of the supply chain through Industry 4.0 technology (i.e. the development of a WEIS supply chain) can reduce FLW. However, given that meso-level causes of FLW are concerned with working relationships between actors within the CFSC, the material covered on game theory and information sharing in Chapter Four and Chapter Eight respectively infers that the meso-level decisions will contribute an element of risk towards customer purchasing habits. Similarly, whilst not immediately visible to the consumer, macro-level issues will also have a huge impact upon both the kinds of food available and the kinds of foods which consumers choose to purchase. Hence, it was concluded that a greater awareness of micro, meso and macro level problems is required in order to reduce and effectively manage global levels of FLW.

10.3. Evaluation of the Hypotheses

Two hypotheses were proposed in Chapter Six. For convenience, these are reproduced below:

Hypothesis One

It is feasible to implement the "bounded rational" DEA model as a benchmarking tool for each of the key issues identified. Hence, we are looking to express each of the key issues identified as affecting the CFSC in terms of a DEA model.

This hypothesis was addressed in Chapter Seven, where we sought to compile and/or develop existing models for each of the issues identified into a form that can be expressed as a DEA model, or which already exist as hybrid AHP-DEA models. Although this study has not implemented the algorithms in software, the novelty resides in the fact that once a DEA model has been identified, it can readily be transformed into a "bounded rational" DEA model based on an "upper" and "lower" bound of belief degree. Hence, we have demonstrated that it is feasible to implement the "bounded rational" DEA model as a benchmarking tool for each of the key issues identified within the CFSC.

Hypothesis Two

It is feasible to construct an alternative to the SCOR model, based on four decision matrices, Managerial, Logistical, Relationships and Innovation, but which incorporates AHP or uncertain AHP to determine the relative hierarchy of the key performance factors (i.e. a "league table", which compares the company's KPFs with those of its competitors), and which uses "bounded rational" or uncertain DEA to establish realistic thresholds in order to assess the performance of each performance factor. In addition, the new model needs to satisfy the following conditions:

5. It should adopt a supply chain wide approach;
6. It should incorporate a network-orientated logistics-controlling mechanism;
7. It should address sales and marketing, product development, research and development and some elements of post-delivery customer support;
8. It should consider multiple perspectives of the problem owners and allow for the time phasing of objectives.

Although we have demonstrated that a viable alternative to the SCOR model could be implemented, the SCOR model itself remains the leading model for measuring supply chain performance. Hence, the alternative model would have to be introduced gradually alongside the existing SCOR model. However, this is consistent with a philosophy of continuous improvement. Clearly, the next phase of study would be a full software implementation where the alternative model's performance is evaluated alongside that of an existing SCOR implementation. However, we do stress that the "bounded rational" approach upon which the alternative model is based does offer a theoretical improvement over the existing SCOR model for reasons already outlined in Chapter Five and Chapter Seven.

10.4. Key Research Findings

In Chapter Six we outlined our methodology, where we stated that customer purchasing habits are behaviour-orientated, whilst any models proposed for the CFSC must be design-orientated in order to meet customer demand. Hence, it follows that the effectiveness of the models proposed cannot be fully assessed without some understanding customer behaviour patterns. Hence, our next consideration concerns how much scope have we allowed for customer behaviour to influence the CFSC model within the issues identified.

10.4.1. Assessing the Impact of Customer Behaviour upon the CFSC

Of the six key issues within the CFSC identified in Chapter Two, the following key issues can be said to be affected by customer behaviour:

1. Demand forecasting;
2. Customer satisfaction;
3. Price fluctuation.

The other three issues (i.e. technological challenges, shelf life monitoring and food waste monitoring) are design-orientated issues.

Demand forecasting was introduced under section 2.2.4., whilst DEA approaches towards managing demand forecasting were discussed under section 7.5.1.4. In particular, we discussed Xu and Ouenniche (2012)'s super-efficicient DEA method, which is based on maximising goodness of fit and minimising biasedness without decreasing the ability of predicting the correct sign (i.e. whether demand for a specific product is increasing or decreasing). We compared and contrasted this technique with Yawe (2010)'s model for maximum proportional input reduction and demonstrated that the Xu and Ouenniche (2012) super-efficiency DEA forecasting model can be adapted into a tracking model, based upon minimising $1 - \theta_k^*$ for each DMU.

Customer satisfaction was discussed under section 7.5.1.5. Here we considered the Lewis and Mazvancheryl (2011) DEA model for measuring the efficiency of the customer satisfaction process, which itself is based on the American Customer Satisfaction Index (ACSI) Model (Fornell 1996). In section 7.5.1.5.1. we also considered ways of measuring customer satisfaction based on Reiner (2005)'s observation that is more expensive to attract a new customer than to keep an already existing one. Hence, Reiner (2005) suggests that customer retention is what businesses should really be focusing upon.

Price fluctuation was discussed in section 7.5.1.6. Accordingly, a number of techniques were introduced, including Olson and Wu (2011)'s seven-step DEA-based algorithm which acts as a "filter" in determining the most cost-effective supplier under uncertain conditions, and the Wong and Wong (2007) DEA "slacks" model.

Chapter Three demonstrated that a pure "pull" system would be a commercial disaster for companies operating within the CFSC. Hence, whilst customer demand is necessary to ensure customer "pull" (by definition) the choice available to customers must therefore be drawn from the best-available MTO-MTS compromise, which infers that a hybrid model is required.

Chapter Four discussed Mitchell (1998)'s categories of risk to the customer. Hence, we have assessed how customer demand is one of the major causes of supply chain uncertainty, but also how overall perceived risk to the consumer itself impacts upon customer behaviour.

Chapter Five discussed methods to measure and improve the performance of the existing supply chain model. In particular, we considered Shashi and Singh (2015)'s suggestion that SCM focuses on how firms use their supplier's processes, technology, capability to enhance a competitive advantage. Yet given how customer demand impacts upon the overall uncertainty of the supply chain model it follows that companies will only obtain a competitive advantage through a better understanding of customer behaviour.

However, in section 7.7.2. we discussed how an unprecedented event has the capacity to impact upon key performance measures, with the examples of a crop failure or a food contamination scandal having a knock-on effect.

Chapter Eight suggested that the game theoretic models discussed (i.e. Cournot, Stackelberg and Bertrand model games) all depend upon access to customer demand information.

However, Chapter Nine indicated that issues such as managing FLW within the wider context of sustainable systems and the implementation of SFSCM are essentially driven by customer demand. In other words, the high demand for fast food and "convenience" food can only be maintained so long as ignorance towards the benefits of healthier and more sustainable food alternatives is maintained.

10.4.2. Assessing the Impact of Incomplete Data

Although we have anticipated that the models used will be working with incomplete data, we have not yet discussed what form they take

10.4.2.1. Types of Data Incompleteness

If Y is the complete data set, Y_o is the observed portion of Y, and Y_n is missing data of Y. Hence, we have:

$$Y = \{Y_o, Y_n\}$$

(Marlawa 2009, 4).

Hence, we have three types of missing data mechanisms to consider:

1. Missing at Random (MAR);
2. Missing Completely at Random (MCAR);
3. Missing Not at Random (MNAR).

Each of these will be discussed below.

10.4.2.1.1. Missing at Random (MAR)

This is when there is a systematic relationship between the propensity or cause of data Y_o and Y_n but not the with the missing data itself. Hence, if M is the missing value indicator, $M = 1$ if Y is observed and $M = 0$ if Y is missing. Hence, MAR is expressed as

$$P\{M|Y_o, Y_n\} = P\{M|Y_o\}$$

MAR is also known as an "ignorable" case because the unobserved data can be imputed from the observed data without affecting the overall outcome.

10.4.2.1.2. Missing Completely at Random (MCAR)

This is when the missing value indicator M is not related to Y_o or Y_n. Hence, MCAR is expressed as

$$P\{M|Y_o, Y_n\} = P\{M\}$$

Hence, there is nothing systematic about why some data is more likely to be missing than others. In addition, we also note that MCAR data are categorised as "ignorable" because we do not have to include any information about the missing data itself.

10.4.2.1.3. Missing Not at Random (MNAR)

This is when the missing value indicator M is related to the missing values themselves. Hence, we can state that for MNAR

$$P\{M|Y_o, Y_n\} = P\{M|Y_n\}$$

MNAR is also known as the "non-ignorable" case because a reason for the missing data has to be modelled as the data is interpreted. Hence, MNAR has potentially catastrophic consequences for missing data. However, it is difficult to distinguish between MAR and MNAR without additional information (i.e. without knowing that the information is missing).

Hence, MNAR can lead to biased results depending on the extent of the missing data. Hence, MNAR reminds us that there is always the possibility of that one catastrophic result, i.e. a "September 11th" type event or a food contamination scandal, which challenges the robustness and agility of the existing model. Hence, adaptive goal setting based upon Harsanyi (1968)'s reasoning that$G^* \subseteq G$, where $G = \{G_1, \ldots, G_n\}$ is the set of best possible games which can be played, is the most optimal strategy for dealing with MNAR data.

10.4.2.1.4. Joint and Mixed Models

Given that MNAR cases are non-ignorable and can impact upon the validation of a given study, our next concern is how much MNAR the unobserved data contains. Hence, we must assume that a mixture of MAR, MCAR and MNAR data patterns will be present (Verbeke and Molenburghs 2004, 142). Indeed, a pure reliance upon MNAR selection models is "dangerous" (Verbeke and Molenburghs 2004, 153) because the model can only be tested based upon the observed data and does not pay enough attention to the missing data. However, if the missing data largely consists of MAR and MCAR variables, we can employ data imputation methods to replicate the missing data. Roderick and Rubin (2002) list a number of such techniques, which include:

1. The exact least squares method;
2. Yate's method or second summation;
3. The use of formula such as the technique of Allan and Wishart (1930), which is based on a least squares estimate of one missing value in a randomised block design and one missing value in a Latin block design;

4. The use of iteration to find the missing data;
5. Bartlett's ANCOVA method.

For a more in depth discussion of these techniques the reader is referred to Roderick and Rubin (2002).

10.4.2.2. Pattern Mixture Analysis

In addition, Blozis (2011) and Roderick and Rubin (2002) suggest that we consider missing data in terms of pattern mixtures. If $Y = \left(y_{ij}\right)$ is a $(n \times K)$ rectangular data set without missing data, with the ith row $y_i = (y_{i1}, \dots, y_{iK})$ where y_{ij} is the value of variable Y_j for subject i. The missing data indicator matrix $M = \left(m_{ij}\right)$ such that

$$m_{ij} = \begin{cases} 1\ if\ y_{ij}\ is\ observed \\ 0\ if\ y_{ij} is\ missing \end{cases}$$

Accordingly, these patterns of missing data can help us to identity whether the missing data is most likely to be MAR, MCAR or MNAR. Accordingly, incomplete data patterns fall under the following six categories:

1. Univariate nonresponse – this is where the missing data is confined to a single variable. This is also known as the missing experiments problem, or in agriculture it is known as the missing plots problem. Hence, the pattern is said to be Y_K incomplete and Y_{K-1} fully observed.

				?

Figure 10.2. Univariate response pattern.

2. Multivariate two patterns – this is when Y_K is replaced by a set of variables $Y_{J+1}, \dots, Y_K$, all observed or missing on the same set of cases. In particular, this may refer to unit non-response in surveys where a questionnaire is administrated and a subset of individuals does not complete it for whatever reason.

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Figure 10.3. Multivariate two patterns.

3. Monotone – this is where the variables can be arranged so that $Y_{J+1}, \dots, Y_K$ are missing for cases where Y_J is missing, for all $J = 1, \dots, K - 1$. Typically this refers to attrition, where subjects drop out of a survey part way through a study and do not return to the study.

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	?	?	?	?

Figure 10.4. Monotone.

4. General or arbitrary – this is where missing data follows a haphazard pattern.

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Figure 10.5. General or arbitrary.

5. File matching – this refers to the case where variables are never jointly observed. Hence, a correlation between the variables is not possible to predict, which may lead to misleading results.

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Figure 10.6. File matching.

6. Factor analysis – if X represents the set of latent variables that are completely missing and Y represents the set of variables which are fully observed, factor analysis is the multivariate regression of Y on X for this pattern.

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Figure 10.7. Factor analysis.

For further information refer to Roderick and Rubin (2002), Verbeke and Molenburghs (2004), Marwala (2009).

10.5. Key Findings and Observations

In this section we provide an overview of the major opportunities, benefits and implications of the study and how these factors will influence the future direction of the research. In terms of the proposed model, the following observations are made:

1. It is feasible to develop a system which manages the key issues of the CFSC by exploiting Industry 4.0 technology.

2. This study has proposed many viable solutions for managing key issues of the CFSC within acceptable tolerance limits. However, this model is most effective when coupled with a philosophy of continuous improvement.
3. Hence, our proposed solution is based upon a "bounded rational" model which provides an optimal level of efficiency for system operation when working with uncertain or incomplete data. Hence, our model is based upon establishing acceptable threshold levels for the concerns which have been identified.
4. Our "bounded rational" model is a development of the Sueyoshi et al (2009) hybrid AHP-DEA auditing algorithm, but is intended for use with incomplete data sets.
5. Our algorithm is intended for use as a benchmarking tool for improving the overall efficiency levels of the supply chain performance by considering every aspect of the business model as an input-output ratio.
6. Whilst we can provide an alternative to the SCOR model for managing supply chain performance, any alternative model would have to be introduced gradually alongside the existing SCOR model.

Hence, in order to complete this project we need to establish a hierarchy of the various models we have developed in order to show how they construct the overall model.

10.6. A Hierarchy of the Models

We are now in a position to structure a hierarchy of models for the proposed solution. If we begin at top-most level, we have the following categories:

1. Identifying key issues within the CFSC;
2. Defining an effective supply chain strategy;
3. Determining the decoupling point in the MTO-MTS hybrid;
4. Measuring and improving supply chain performance;
5. Identifying main areas of risk;
6. Identifying key drivers for change;
7. The modified dissatisfaction equation.

Accordingly, these steps envisage a repeating process of continuous improvement, with the dissatisfaction equation giving rise to the need to re-evaluate the key issues within the CFSC and the supply chain strategy. Hence, the hierarchy can itself be constructed from the discussions given in this study.

10.6.1. Identifying Key Issues within the CFSC

This structure was developed in Chapter Two and Chapter Seven and is given as follows:

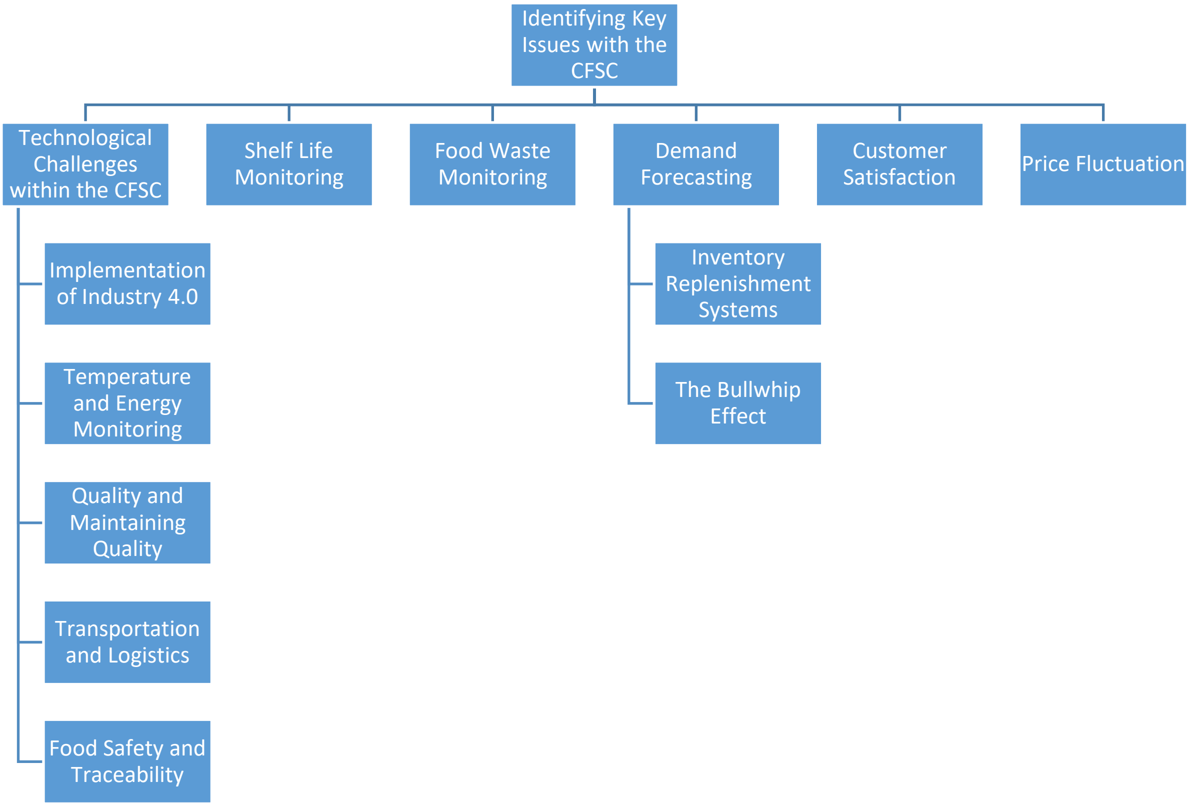

Figure 10.8. Structure for the "Identifying Key Issues within the CFSC" algorithm.

10.6.2. Defining an Effective Supply Chain Strategy

This develops from Chapter Four and Chapter Eight and follows the following structure:

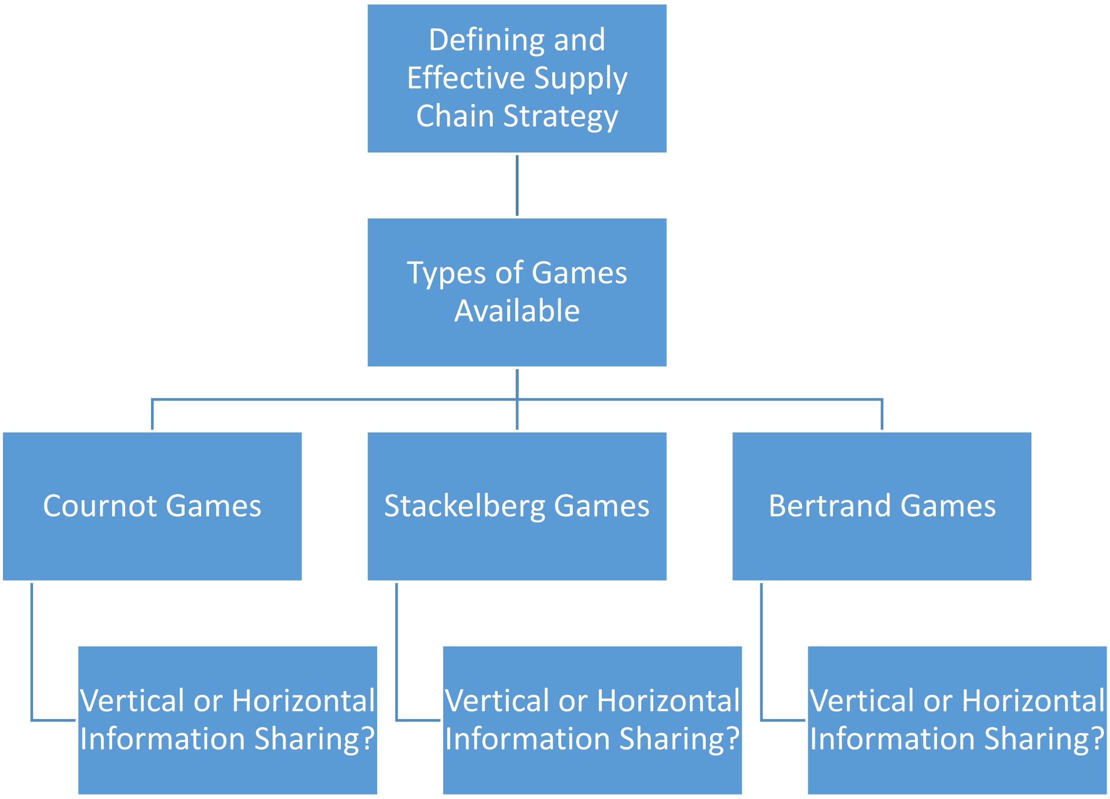

Figure 10.9. Structure of the “Defining and Effective Strategy” algorithm.

10.6.3. Determining the decoupling point in the MTO-MTS hybrid

This develops from Chapter Three and in Chapter Seven and follows the structure:

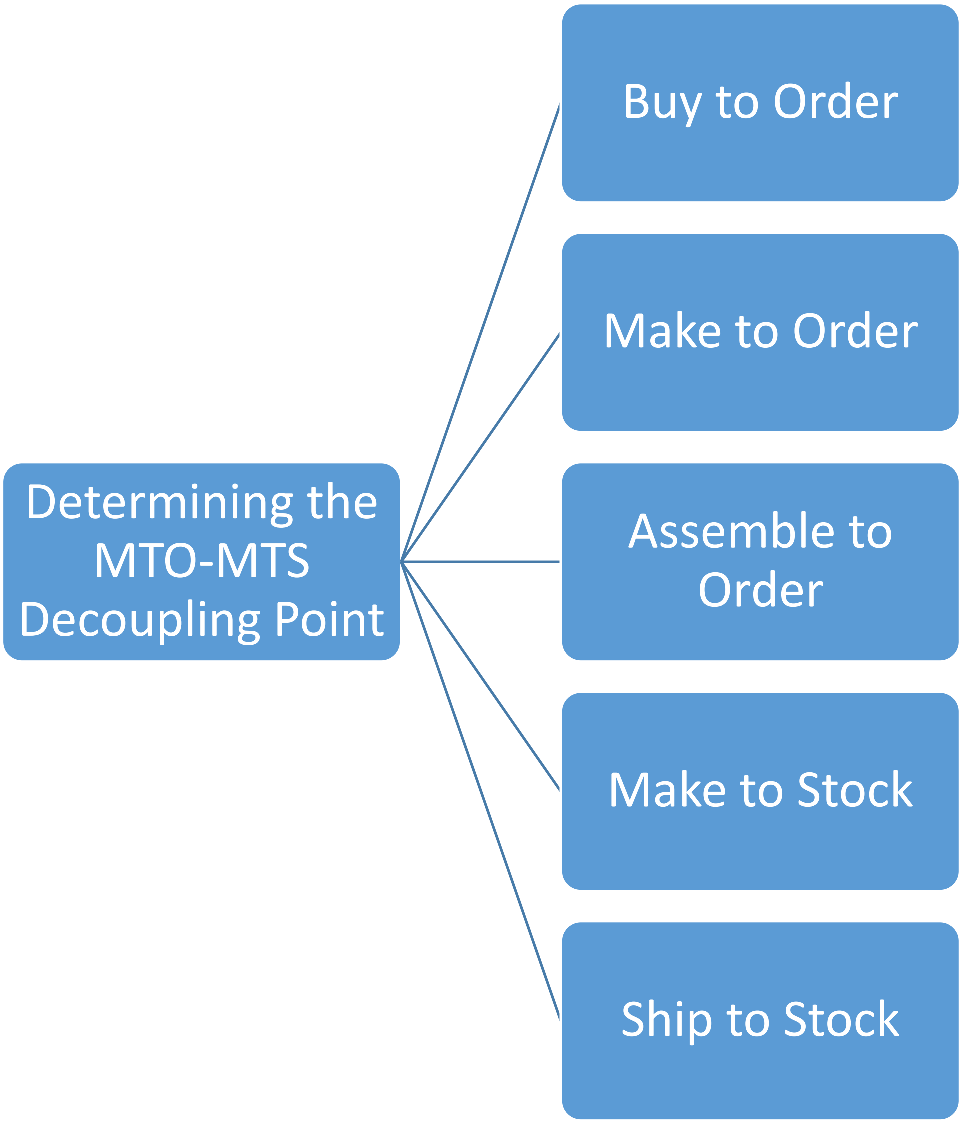

Figure 10.10. Structure of the “Determining the MTO-MTS Decoupling Point” algorithm.

10.6.4. Measuring and Improving Supply Chain Performance

This was discussed in Chapter Five and in Chapter Seven and follows the following structure:

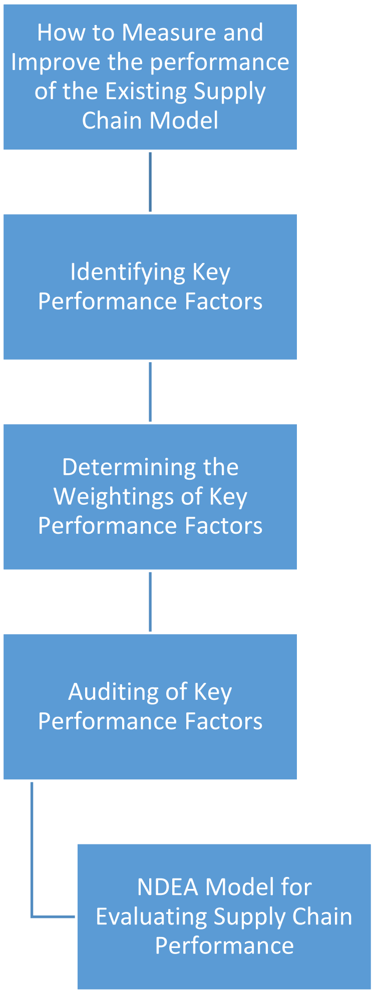

Figure 10.11. Structure of the "How to Measure and Improve the Performance of the Existing Supply Chain Model" algorithm.

Hence, for convenience Figure 5.3. is reproduced below as Figure 10.12 to indicate how key performance factors might be identified:

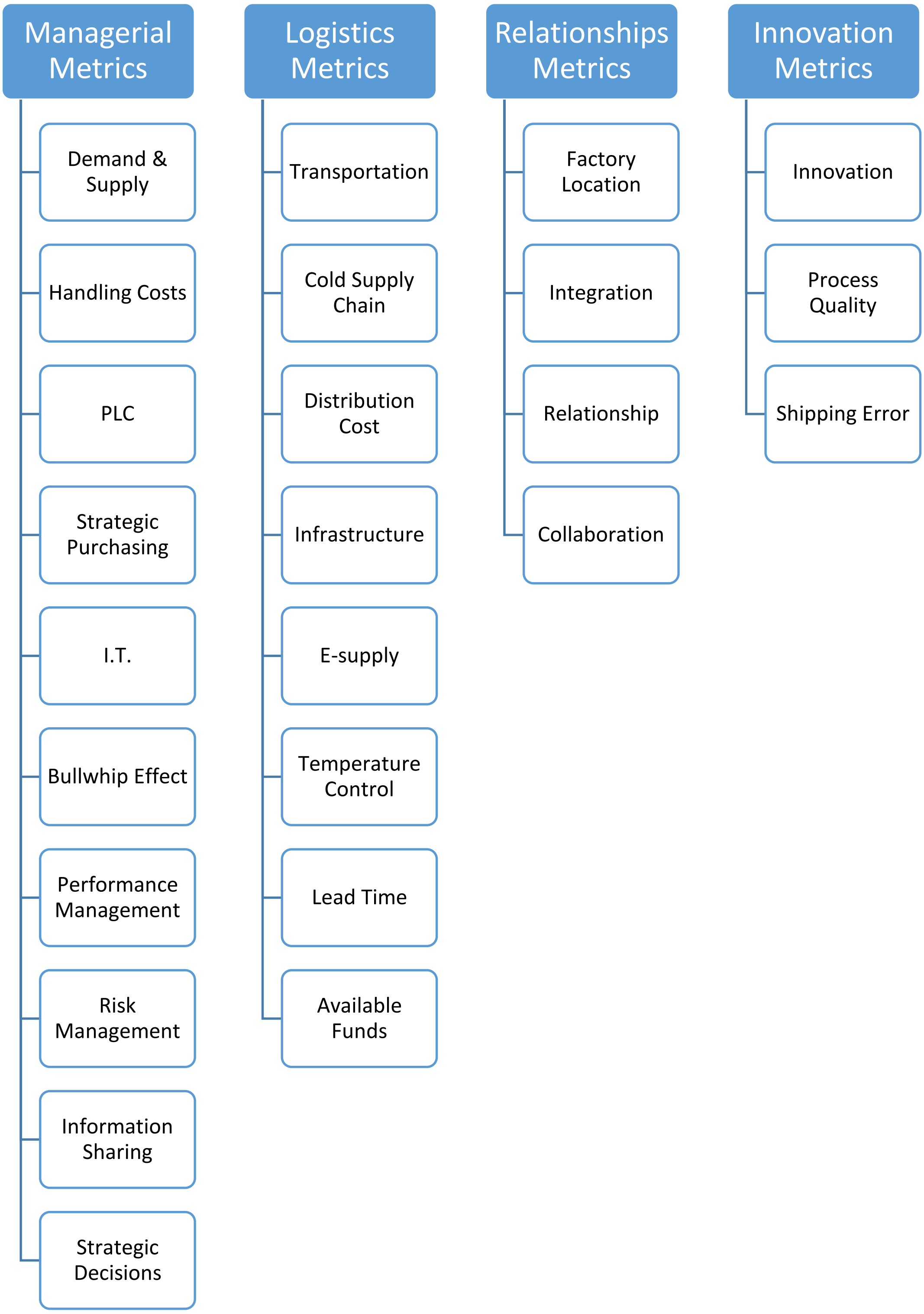

Figure 10.12. Reproduction of Figure 5.3. to indicate how key performance factors might be identified.

As can be seen, this layout makes it clear where and why certain key performance factors can be added to or deleted from the supply chain model.

10.6.5. Identifying Main Areas of Risk

This was discussed in Chapter Four and Chapter Seven, whilst Chapter Nine introduced the concept of micro, meso and macro level uncertainty as affecting the business model. Hence, our model which derives from the Cunningham equation adopts the following structure:

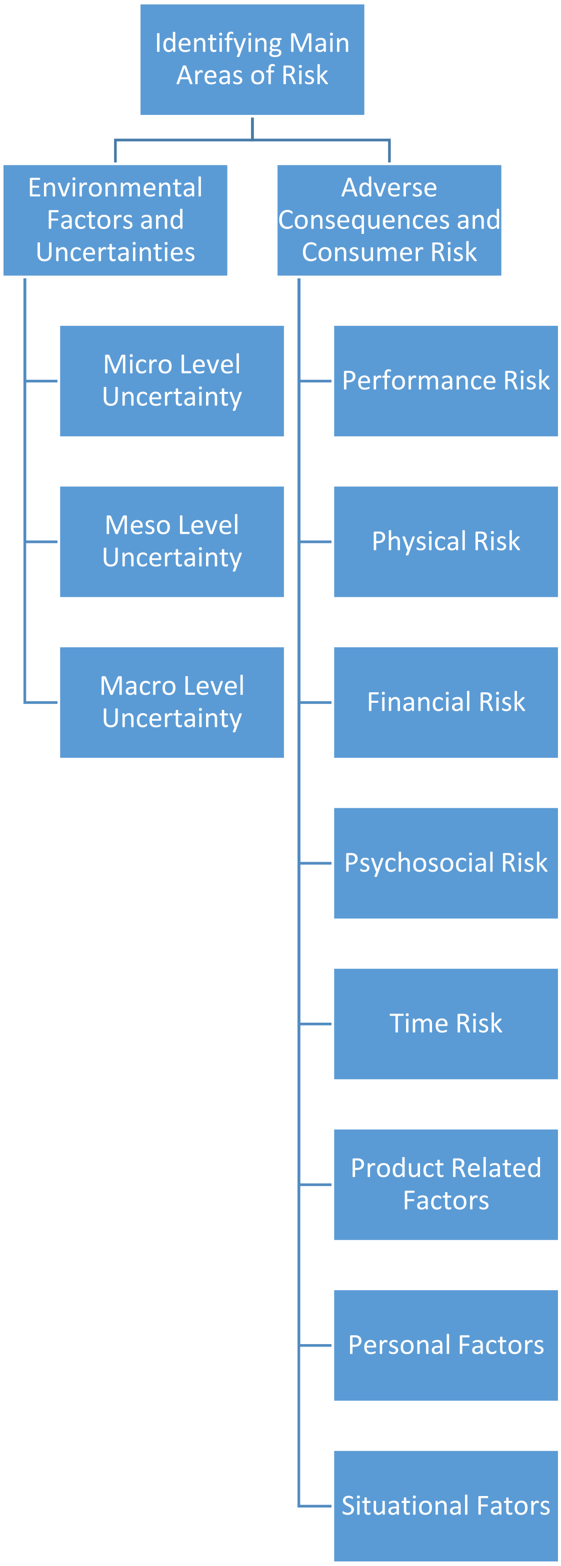

Figure 10.13. Structure of the “Identifying Main Areas of Risk” algorithm.

Hence, we can continue to expand each of these categories as the system evolves.

10.6.6. Identifying Key Drivers for Change

This was briefly discussed in Chapter Two. However, if we follow Kearney (2010)'s reasoning we notice that change is driven by two key factors: socio-economic factors and supply chain factors. Hence, if we take the outputs from the previous five stages, we can use these to identify the main areas of the business model which need improving. Hence, we have

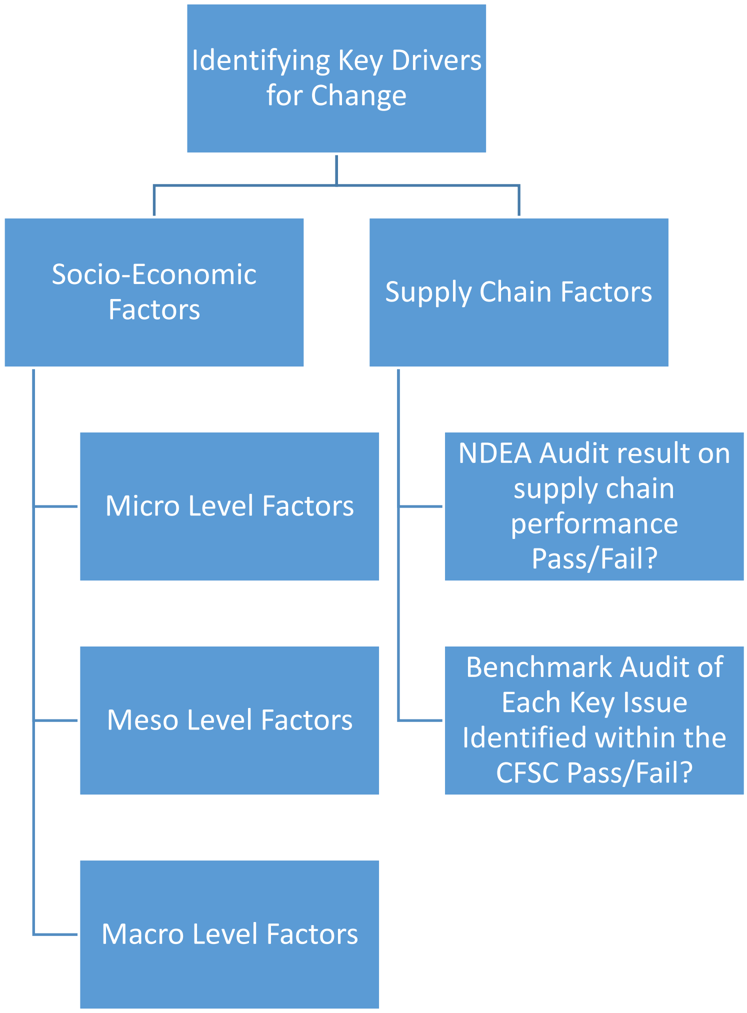

Figure 10.14. Structure of the "Identifying Key Drivers for Change" algorithm.

10.6.7. The Modified Dissatisfaction Equation

The modified dissatisfaction equation was briefly discussed in Chapter Nine. However, it is very similar to the model for identifying key drivers for change. The difference is that the modified dissatisfaction equation is motivated by an adaptive goal setting algorithm linking Rahwan et al (2007)'s lemma to Harsanyi (1968)'s theory of incomplete games

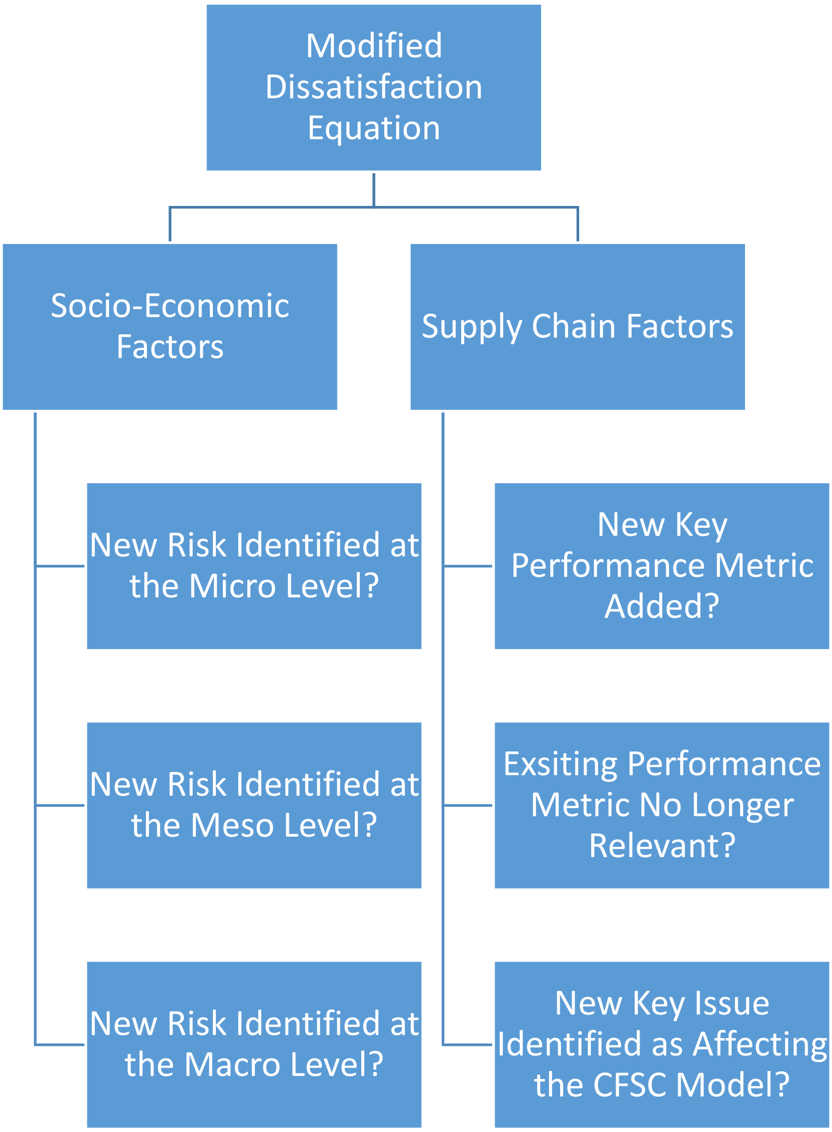

Figure 10.15. Structure of the "Modified Dissatisfaction Equation" algorithm.

10.7. Future Work

The next phase of this project would be a full software implementation of the models developed during this study. Yet if we return to Atzori et al (2010)'s suggestion of an intersection of "Things", "Semantics" and "Internet", the next logical extension of this work would be the integration of natural language processing (NLP) into the system. If we consider the most likely environments into which the system is intended to be deployed, such as warehouses, bars and restaurants, then we must also consider that its primary operatives are less concerned with technical knowledge and more concerned with the day-to-day running of their businesses. Hence, we are considering a system in which the monitoring of "Things" and protocols of "Internet" are less visible to the user.

Much of the software to enable a NLP implementation is currently available, such as NLTK, or the Natural Linguistic Tool Kit, which features a number of software patches for the Python programming language. However, according to Liddy et al (2003) there remain a number of challenges which need to be overcome, including:

1. Machine Reading – such that the system is able to read and learn text. Much of this work is very closely related to our discussion of Harsanyi games and Rahwan et al (2007)'s lemma for adaptive goal setting.
2. Socially Aware Language Understanding – accordingly, the system must be able to "recognise, interpret and respond appropriately" to all contexts in which the language is encountered (Liddy et al 2003, 5). Hence, we would need to establish a range of prompts from the system, as well as the types and forms of questions which a user can ask the system.

3. Annotation Science – this issue is concerned with knowledge representation. Liddy et al (2003) present two research questions which inform this problem, which are:
    a. How do we know which phenomena to focus upon, develop representations for them, and ensure consistency of the representations?
    b. How do we acquire the massive amounts of training data required in order to sustain progress?
4. Intersections between NLP and Other Areas of Artificial Intelligence – currently, many of the basic questions concerning NLP applications are developed independently. Whilst we might expect Industry 4.0 to bring these diverse disciplines together, individual research groups tend not to read the relevant literature of the other groups.

Hence, there remain many gulfs between knowledge disciplines, which need to be rectified before this level of implementation can be achieved.

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